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COMPARATIVE FEATURES OF METABOLISM AND FUNCTIONING OF THE EXTERNAL RESPIRATION IN YOUNG MALE RESIDENTS OF DIFFERENT CLIMATIC AND GEOGRAPHICAL AREAS OF RUSSIAN NORTHEAST

ABSTRACT

The environmental and climatic conditions of the North impose a special effect on the functioning of the body systems placing high demands on maintaining the internal constancy of the human body. Special attention should be paid to the system of external respiration which is the first to be adversely affected by cold air as well as possible changes in the metabolism of people who live under these climatic extremes for a long time. The varying degree of exposure to environmental factors, from moderate cold pressure to extreme combined effects, which have an influence on the whole body should be taken into account. The **purpose** of this work was to identify the peculiarities of metabolism rearrangements as well as the respiratory system functioning in young healthy individuals permanently residing in different climatic and geographical zones of northeastern Russia which differ significantly in the weather severity index.

Based on a study of spirography and indirect calorimetry, a comparative study was conducted among 17-19 year old 678 young men from the North born Caucasians in their 1st and 2nd generations residing in Magadan region and Chukotka Autonomous Region. An analysis of the data showed that compensatory adaptive changes in physiological systems were observed in young men of all the examined groups. However most of all they were typical for residents of the continental part of Magadan region whose adaptive shifts were aimed at minimizing the pronounced cold effect of this climatic area. At the same time, the young men of this group were found to have the highest daily energy consumption indicators that ensure the maintenance of the increased heat production. Besides, they demonstrated the maximum permeability of the distal bronchioles among all the young surveyed men, which is necessary both for adequate oxygen supply to the body and protection from low ambient temperatures.

Keywords: young males, external respiration system, indirect calorimetry, metabolism, North.

One of the leading abiotic factors of the North which can lead to the depletion of compensatory and regulatory mechanisms as well as to disorders in constancy of the internal environment is the cold factor [2]. At the same time, the special structure of the climate of northern regions undoubtedly increases the “price of adaptation” which is not always experienced successfully by everybody [8]. Northeastern Russia is a vast territory, significantly different in environmental and climatic conditions as well as the degree of impact of these abiotic factors on humans. Magadan Region (MR) can be divided into significantly different subzones: the coastal part with the city of Magadan which is cyclonic and characterized by constant winds and relatively high air temperatures in winter (-15° C), and the continental part with the town of Susuman suggesting the almost absence of the wind exposure, but extreme temperatures in both summer (+36° C) and winter (-53° C) as well as relatively low humidity [10]. It should be distinguished the coastal zone of Chukotski Autonomous District (CAD, Anadyr) referring to the sub-arctic climate zone. These unfavorable conditions force humans to use additional means of protection against the influence of the above environmental factors [13]. However, with respect to the respiratory system, this practice is not applicable and it is that very system which is the first to be exposed to the negative effects of cold air. In this regard, the purpose of our work was to identify peculiarities of respiratory system rearrangements as well as metabolism of people permanently residing in different climatic and geographical zones of northeast Russia.

Materials and methods. To achieve this goal, 622 healthy young men aged 17-21 were comprehensively examined, all being Caucasians born in the North in the 1st and 2nd generations, permanently residing in the northeast of Russia. The first group were permanent residents of the city of Magadan (the coastal part of Magadan Region), the second group included persons from the town of Susuman (the continental part of Magadan Region), and the third group was made up of the young men from the city of Anadyr (the coastal part of the Chukotski Autonomous District).

The study was conducted in a room with a comfortable temperature. The method of spirometry was used to assess the function of external respiratory (FER), which is the main instrumental method to determine the possible presence of any diseases of the respiratory system [15]. Indicators of respiratory function were recorded in an open system on the principle of “volume-flow” using a computer spiroanalyzer KM AP 01 "Diamant-S" (Russia). Due values were calculated using the method of R. F. Clement (et al.) being the generally accepted standard in the Russian Federation for the evaluation of spirographic samples [3]. The following indicators were analyzed: the time taken to perform a calm expiration that is Vital Capacity, (T_{VC}, s), and forced expiration that is Forced Vital Capacity, (T_{FVC}, s); Vital and Forced Capacity of the lungs (VC, FVC, L); Peak Expiratory Flow (PEF, L/s); Forced Expiratory Volume in the first second (FEV_1, L); Forced Expiratory Flows at 25%, 50%, 75% ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$, L/s); Medium Expiratory Flow ($MEF_{25\text{-}75\%}$, L/s) as well as two Indices of bronchial obstruction, Tiffno and Gensler (IT, IG, %).

The levels of metabolic processes in the body as well as some indicators of external respiration were estimated using the Medgraphics VO2000 metabolograph (USA) based on the “indirect calorimetry” method [14]. Energy consumption was determined at rest in a day (REE/day, kcal) both in kilocalories and as a percentage of the norm (REE/Pred, %). The Respiratory Rate (RR, cycle/min), Body Temperature and Pressure Saturation Volume (V_t BTPS, mL), Minute Volume of Body Temperature and Pressure Saturation (VE BTPS, L), Respiratory Quotient (RQ, arb. units), Oxygen Consumption and Carbon Dioxide Emission (VO_2, VCO_2, mL/min), the relative concentration of carbon dioxide and oxygen in exhaled air (FET CO_2, FET O_2, %), the proportion of Fats and Carbohydrates in the energy substrate (Fat/REE, CHO/REE ,%), Oxygen Consumption per kilogram of weight, (Ox. Cons/kg, mL/kg), Oxygen Utilization Factor (Ox. Util. Fact., mL/L).

The study was carried out in accordance with the principles of the Helsinki Declaration. The study protocol was approved by the Ethical Committee for Biomedical Research at the NESC of the Far-Eastern Branch of the Russian Academy of Sciences (December 4, 2012; Protocol No. 3). All young men underwent research voluntarily.

Statistical data processing was performed using Microsoft Excel 2013. The average values of indicators (M) and average errors (± m) were calculated. Significance of differences was assessed by Student’s t-test for independent samples. The null hypothesis of the presence of differences among the presented samples was accepted at $p < 0.05$.

Results and discussion. Table 1 presents indicators of the function of external respiration in young men of different climatic and geographical zones. From the presented data it is clear that the smallest part of the differences was recorded for regions with a coastal climate, and the largest one when compared with the continental climate region. In the absence of significant differences in the vital capacity of the lungs, the Susuman residents had the lowest values for the forced capacity, the forced expiratory volume in the first second and the peak expiratory flow. The maximum values of them were observed in the residents of Anadyr. It should be noted that this was noted both in terms of actual and relative (as a percentage of the proper indicator) values. Considering the fact that the respiratory airways have the greatest surface contact with the external environment, this fact of reducing of the main characteristics of the bronchopulmonary system should be considered as a protective reaction of the body against the extremely low atmospheric air of Susuman [11]. At the same time, the indicated decrease in airflow of the upper structures of the lungs was compensated by the expansion of the distal bronchioles ($FEF_{75\%}$) the diameter of which in Susuman residents reached 150 % increase. The increase in the patency of the small bronchi was also observed in the young men of the cities of Magadan and Anadyr, but such high values in $FEF_{75\%}$, as compared to the inhabitants of the central European part of Russia, could be observed only in the inhabitants of the continental part of Magadan Region. In addition to increasing in the amount of warm air remaining in the lungs, this increase in bronchoperfusion should certainly be considered as a mechanism to protect the lungs from pneumosclerotic manifestations, when in conditions of very low temperatures of Susuman there is an elevated production of surfactant necessary for moistening and warming the dry cold air [9]. Besides, an increase in the caliber of the distal bronchi contributes to the sustainable maintenance of the more efficient laminar nature of the air flow, which ultimately has a positive effect on the diffusion processes in the respiratory zone of the bronchopulmonary tree [1].

Table 2 shows the indicators of indirect calorimetry of the examined young men. Analysis of the data shows that, as in the case of the characteristics of the function of external respiration, most of the differences were observed among groups of young people from the continental and

Table 1

Indicators of the function of external respiration in 17-21 year old male residents of Magadan, Susuman and Anadyr (M ± m)

Indicator	Habitat of the examinees			Significance of differences among groups		
	Magadan (1) n = 359	Susuman (2) n = 63	Anadyr (3) n = 42	1-2	2-3	1-3
T_{VC}, s	1.78±0.05	1.62±0.05	1.89±0.07	p<0.01	p<0.01	p=0.21
VC, L	5.12±0.04	5.13±0.1	4.99±0.14	p=0.93	p=0.42	p=0.37
VC, %	103±0.6	103±1.58	103±2.06	p=1	p=1	p=1
T_{FVC}, s	1.38±0.04	1.13±0.05	1.8±0.06	p<0.001	p<0.001	p<0.001
FVC, L	4.94±0.04	4.71±0.1	5.07±0.14	p<0.05	p<0.05	p=0.37
FVC, %	102±0.64	97±1.65	108±2.2	p<0.01	p<0.001	p<0.01
FEV_1, L	4.51±0.03	4.26±0.07	4.5±0.14	p<0.01	p=0.13	p=0.95
FEV_1, %	106±0.6	101±1.31	107±2.59	p<0.001	p<0.05	p=0.71
T_{PEF}, s	0.14±0.01	0.26±0.01	0.13±0.1	p<0.001	p=0.36	p=0.92
PEF, L/s	9.92±0.08	9.12±0.16	10.17±0.29	p<0.001	p<0.01	p=0.41
PEF, %	108±0.81	100±1.54	113±2.44	p<0.001	p<0.001	p=0.06
$FEF_{25\%}$, L/s	8.91±0.08	8.51±0.17	8.73±0.27	p<0.05	p=0.94	p=0.52
$FEF_{25\%}$, %	109±1	104±1.87	108±2.64	p<0.05	p=0.22	p=0.72
$FEF_{50\%}$, L/s	6.32±0.1	6.31±0.15	5.73±0.2	p=0.96	p<0.05	p<0.01
$FEF_{50\%}$, %	113±1.18	111±2.54	106±3.71	p=0.48	p=0.27	p=0.07
$FEF_{75\%}$, L/s	3.81±0.05	4.16±0.13	3.32±0.15	p<0.05	p<0.001	p<0.01
$FEF_{75\%}$, %	131±2.5	150±4.63	114±5.3	p<0.001	p<0.001	p<0.001
$MEF_{25-75\%}$, L/s	6.34±0.06	6.29±0.13	5.54±0.2	p=0.73	p<0.01	p<0.001
$MEF2_{5-75\%}$, %	115±1.02	113±2.17	112±3.57	p=0.41	p=0.81	p=0.42
IT, %	88±0.42	84±0.99	86±0.89	p<0.001	p=0.14	p=0.12
IG, %	93±0.5	93±0.75	88±0.85	p=1	p<0.001	p<0.001

Table 2

Indicators of indirect calorimetry in 17-21 year old male residents of Magadan, Susuman and Anadyr (M ± m)

Indicator	Habitat of the examinees			Significance of differences among groups		
	Magadan (1) n = 84	Susuman (2) n = 51	Anadyr (3) n = 23	1-2	2-3	1-3
REE/day, kcal	2145±59.5	2344±63.6	2048±74.5	p<0.001	p<0.01	p=0.31
REE/Pred, %	117±2.92	131±3.02	115±4	p<0.01	p<0.01	p=0.69
RQ, arb. units.	0.86±0.01	0.79±0.01	0.89±0.03	p<0.001	p<0.01	p=0.35
RR, cycle/min	14.5±0.49	18.2±0.72	14.7±0.8	p<0.01	p<0.01	p=0.83
Vt BTPS, mL	686±26.4	544±18.2	640±28.5	p<0.001	p<0.01	p=0.24
VE BTPS, L/min	9.22±0.31	9.08±0.27	9.2±0.56	p=0.74	p=0.85	p=0.98
V CO_2, mL/min	263±9.47	267±8.34	253±10.8	p=0.75	p=0.31	p=0.49
V O_2, mL/min	304±8.05	338±9.2	290±11	p<0.01	p<0.01	p=0.31
FET CO_2, %	3.59±0.05	3.72±0.07	3.6±0.11	p=0.14	p=0.36	p=0.93
FET O_2, %	16.68±0.07	16.24±0.09	16.7±0.19	p<0.001	p<0.05	p=0.92
CHO/REE, %	52±4.52	33±4.01	53±6.36	p<0.01	p<0.01	p=0.9
Fat/REE, %	48±4.48	67±4.01	47±6.33	p<0.01	p<0.01	p=0.9
Ox. Cons/kg, mL/kg	4.27±0.1	5±0.13	4.2±0.16	p<0.001	p<0.001	p=0.71
Ox. Util. Fact., mL/L	33.8±0.6	37.8±0.83	33.3±1.72	p<0.001	p<0.05	p=0.79

coastal areas. No significant differences through the groups from Magadan and Anadyr were found. The energy consumption at rest (REE) among the young men of all the three examined groups was higher than the proper values calculated using the Harris-Benedict formula [12]. It is noteworthy that the highest values of metabolism (131%) were demonstrated by the residents of Susuman which was achieved due to the more energy efficient lipid type of metabolism (Fat/REE). Under the North conditions, the transition of basic metabolism from carbohydrate to fat type is observed in aboriginal ethnic groups. The latter type, in conditions of extremely low temperatures of the continental climate zone, allows synthesize ATP more efficiently, optimally implementing the mechanism of maintaining the thermal balance of the internal environment of the body [5]. In the groups of the cities of Magadan and Anadyr, carbohydrates were the predominant energy substrate, which is also evident from the higher rates of respiratory quotient (RQ).

Of special note that, against the background of increased oxygen consumption by the bodies of young men from Susuman (by indicator of FET O_2), maintenance of VE BTPS was achieved not due to a more effective BTPS volume, but due to an increase in economically less favorable respiratory rate [7]. Apparently, a significant V_t BTPS decrease found in them compared to the young men of other groups is explained by the implementation of the strategy to protect the lung tissue from the effects of low ambient air temperatures. It is noteworthy that an increase in RR in this case cannot compensate for the lost volume of air entering the respiratory zone of the bronchial tree since shallow and frequent breathing results in ventilation of mostly anatomically dead space while the alveolar portions of the lungs remain unaffected. It becomes obvious that the mechanism for maintaining an adequate level of oxygen supply to the body at simultaneous protection of the lung structures from exposure to exogenous factors is the improved oxygen utilization by the body's tissues seen in oxygen utilization index (Oh. Util. Fact.) [6]. A significant increase in this value shown by the subjects from Susuman against the background of a growth in O_2 consumption per kg of the body weight (Ox. Cons/kg) indicates an increase in the diffusion of oxygen between the alveolar air and blood, which fully ensures the increased energy costs of the organism at low temperatures of the continental natural climatic zone.

Conclusion. Thus, the conducted studies have shown that the adaptive shifts in the body system functioning observed in permanent residents of northeastern Russia increase with increasing the extremes of environmental and climatic factors. At the same time, for most indicators of the function of external respiration and energy metabolism, there were no significant differences among the young men living in the coastal climatic zones of Magadan Region and the Chukotski Autonomous District. The vector of functional rearrangements in persons living in the continental climate zone is aimed at protecting the lungs from obstructive and sclerotic lesions (limiting the depth of breathing, reducing the lung volume characteristics) on the one hand, and adequately providing of the body needs with increased oxygen and improving its delivery to organs and tissues (elevated O_2 Cons. and Ox. Util. Fact.) on the other hand. At the same time, this interaction of functional systems under conditions of extremely low temperatures is an example of effectively maintaining of the homeostatism of the internal environment of the body, which is bringing the residents of this territory closer to the "polar metabolic type" [4].

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