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Hemodynamic aspects of compensatory reactions of human cardiovascular system in the conditions of postural loads

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Abstract

Introduction. The aim of the work was to study the features of central hemodynamic reactions and regulatory mechanisms in persons with hypo- and hyperkinetic blood circulation and different physical status under postural loads.

Methods. The parameters of central hemodynamics and spectral characteristics of the heart rhythm were applied. Healthy men aged 18–21 years with different physical status were involved.

Results. Significant differences were established in adaptive reactions of people with different types of blood circulation and physical status in the conditions of postural loads. Adaptive reactions of central hemodynamics in individuals with the hyperkinetic compared with hypokinetic type of blood circulation in the head-up-tilt position were characterized by more intracardiac and vascular tension and less involvement of the higher vegetative centres. The surveyed persons with the hypokinetic type of blood circulation under these conditions were characterized by lower vascular activation and greater involvement of systemic extracardiac regulation mechanisms. The compensatory reactions of the cardiovascular system in the head-down-tilt position of people with the hypokinetic type of blood circulation, especially athletes, were characterized by a lower activity of the contractile function of the heart and the participation of extracardiac mechanisms of regulation, and those with the hyperkinetic type – by more prominent switching of the higher regulatory centres of the central nervous system and humoral nervous centres on the background of the tension of self-regulation processes.

Conclusions. The revealed features of compensatory reactions of the cardiovascular system may be useful in the field of clinical and sports medicine, and physical rehabilitation.

Key words: central hemodynamics, cardiac rhythm, hypokinetic and hyperkinetic type of blood circulation

Introduction

At the present stage of scientific research, the elucidation of central hemodynamics (CH) mechanisms continues to remain as one of the unresolved problems of normal and sports physiology and clinical medicine. A large percentage of cardiovascular diseases are conditioned by the discrepancy between adaptive processes that occur in CH [1, 2]. The reasons for such changes may be related to the changes in the functions and structure of the heart, deterioration in the elasticity of the vascular walls of arteries, veins, and capillaries, disorders in the blood circulation regulation system [3]. Among the most dangerous effects are ischemia, cerebral stroke, myocardial infarction, and other diseases that take lives of millions of people annually in the world [4]. An increased interest in the study of CH is associated with the possibility to monitor the functional state of the cardiovascular system (CVS), to provide timely and effective diagnosis and treatment, and to prevent the progression of adverse effects of cardiomyopathies, hypoxic disorders, metabolic disorders, cardiovascular complications [5–9].

The reactions of the blood circulation system are considered to be the leading reactions of the organism when providing compensatory mechanisms to various influences of the environment. The state of CH, the contractile function of the heart, energy supply of the myocardium, the activity of regulatory mechanisms are interconnected and interdependent concepts. CH is considered as a reflection of how much the current functional state corresponds to the ability of supporting homeostasis and effectively regulate functions within given conditions [10, 11]. Among sensitive indicators of CH, a large role is ascribed to the blood circulation indices, obtained during the physical exercise with the change in the position of the body in the space. These indicators reflect the complex interactions of the myogenic, neuronal, metabolic, and humoral factors underlying the autoregulation processes that provide homeostasis [10].

Researchers point out that blood circulation expresses individual peculiarities [12, 13]. Hypo- (HK), eu- (EK) and hyperkinetic (HrK) types of hemodynamics have been identified experimentally [14]. The connections between the hemodynamics types and hypertension development [15, 16], the degree of physical fitness, and the level of athletic qualification were shown [17, 18]. According to experimental data on EK and HK, these types of blood circulation are bound with the highest economic efficiency of the CVS [19], whereas

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HrK has low compensatory properties [20]. There is evidence that with the HK type of blood circulation, the power of left ventricular contractions is small [21]. The results of other authors' studies indicate that the parameters of the circulatory system of examined persons with the EK type of blood circulation more often take an intermediate position between the HK and the HrK types [22, 23].

At the same time, many aspects of the relationship between CH types and environmental factors remain not well-studied [24, 25]. There is only a small amount of information on the study of CH and regulation mechanisms under gravity loads. Such a situation does not allow fully disclosing the features of the blood circulation system in providing compensatory reactions of the body in the ortho- and anti-orthostatic positions of the body, which can provide information about its functional reserves. First of all, it concerns the CH of people with extreme types of blood circulation, which more often show the tense nature of adaptation processes, and therefore are as close as possible to the probability of shifts in adaptation processes and the emergence of cardiovascular pathology. Clarification of the relationship between the type of blood circulation and the effectiveness of the CVS functioning is also important in sport (for the individualization of training programs for athletes) and for non-athletes (for monitoring or predicting possible changes in the cardiovascular activity) [26].

The purpose of the study was to investigate the features of CH reactions and regulatory mechanisms of people with HK and HrK blood circulation and different physical status under postural loads.

Subjects and methods

Subjects

A comprehensive study of compensatory reactions of the CVS was conducted with the methods of thoracic rheoplethysmography with the rheographer ReoCom KhAI Medica (Ukraine) and electrocardiography with the Cardiolab+ device (Kharkiv, Ukraine).

Practically healthy men aged 18–21 years, with different physical status, students of sporting and non-sporting specialties of the Cherkasy B. Khmelnytsky National University in Cherkasy, Ukraine, took part in the investigation.

Procedures

In accordance with the goal of the study, with regard to the cardiac index (CI), 2 experimental groups with different types of blood circulation were formed out of the non-sporting students (biologists, psychologists, programmers) and sportsmen (athletes, football players, basketball players). The participants did not present significant differences in the body area [27]. The size of the groups in accordance with the HK and HrK types of blood circulation was as follows: non-sporting men: group 1, $n = 12$; group 2, $n = 15$; sportsmen: group 3, $n = 14$; group 4, $n = 16$, respectively.

The registration of hemodynamic parameters was performed in the lying position, head-up-tilt and head-down-tilt, obtained with a passive movement on the turntable, respectively, at 90° and –25°. The records contained sequential steps: lying position – head-up-tilt; lying position – head-down-tilt, which paused for 15 minutes. To achieve stabilization of the functional parameters of the CVS, the subject remained in a lying position for at least 5 minutes (signal recording began from the 6th minute). In the conditions of postural loads, the participant was for at least 6 minutes (signal recording began from the 2nd minute). Heart rate (HR), total peripheral vascular resistance (TPVR), mean arterial pressure (MAP), shock (ShI) and heart index (HI) were determined. We also assessed parameters of the spectral characteristics of the heart rhythm (SCHR), the parameters of the total power (TP) of the spectrum in the frequency range up to 0.4 Hz, the spectral power at the frequency of less than 0.05 Hz (VLF, very low frequency), spectral power at the frequency of 0.05–0.15 Hz (LF, low frequency), and spectral power at the frequency of 0.15–0.4 Hz (HF, high frequency). This emerged from the generally accepted notions that the power of HF respiratory waves reflects vagal influences, LF waves – mostly sympathetic vasomotor, baroreflector-modulated self-regulation mechanisms, and VLF wave – the level of activation of supersegmental ergotropic systems.

Statistical analysis

The statistical processing of the obtained results was carried out with the methods of mathematical statistics and the software packages of Excel and Statistica for Windows 8.0. The reliability of the changes and the differences between the comparative values was estimated in accordance with the non-parametric Wilcoxon-Mann-Whitney criterion. The existence of a relationship between the indicators was checked by the calculations of the Spearman correlation coefficient. Differences between groups and the existence of correlation dependence were considered to be reliable at $p \leq 0.05$.

Ethical approval

The research related to human use has been complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki and the World Health Organization recommendations [28], and has been approved by the authors' institutional review board or an equivalent committee.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The analysis of the CH indices obtained in the lying position revealed that the indices of the ShI and the HI of the participants in group 1 in relation to group 2 and the similar indices of subjects in group 3 relative to group 4 were significantly lower ($p \leq 0.05$) (Table 1).

The indicators of HR of non-sporting persons in group 1 were significantly higher as compared with the sportsmen with the same type of blood circulation ($p \leq 0.05$). Indicators of ShI of non-sporting individuals in both groups (1 and 2) in comparison with the similar indicators of the sportsmen (groups 3 and 4) within the limits of the same type of blood circulation were significantly lower ($p \leq 0.05$–0.01). HI of the examined persons in group 4 was significantly higher than that of non-sporting men in group 2 ($p \leq 0.05$). The quantitative values of TPVR in groups 1 and 3 were significantly higher in relation to those in the corresponding groups 2 and 4 ($p \leq 0.05$). No differences were found between the indicators of TPVR of the subjects with different physical status, but with the same type of blood circulation ($p \geq 0.05$). Indicators of MAP of the different surveyed groups were within the normal range and did not differ significantly ($p \geq 0.05$) (Figure 1).

Table 1. Indicators of central hemodynamics and spectral characteristics of the cardiac rhythm (median, upper, and lower quartile) of non-sporting men and athletes with hypokinetic (HK) and hyperkinetic (HrK) types of blood circulation under conditions of lying position

Investigated indicators	Surveyed groups			
	non-sporting men		athletes	
	1 (HK)	2 (HrK)	3 (HK)	4(HrK)
HR (bpm)	61.1# (79.3; 57.1)	60.9 (71.4; 58.2)	50 (59.4; 48.2)	54 (58.5; 50.1)
ShI (ml/m^2)	32.7*# (36.7; 29.2)	49.2# (68.7; 57.2)	38.0* (42.4; 33.8)	62.9 (71.0; 58.3)
HI (l/min/m^2)	2* (2.7; 1.8)	3.0# (3.6; 2.7)	1.9* (2.3; 1.4)	3.4 (3.9; 3.0)
TPVR (din · s · cm^{-5}/m^2)	2.0* (2.8; 1.8)	1.7 (2.1; 1.3)	2.4* (2.9; 2.0)	1.8 (2.3; 1.1)
HF (ms^2)	500.4 (523.2; 483.2)	590.3 (671.4; 526.2)	550.1 (580.1; 510.3)	670.3 (701.4; 626.2)
LF (ms^2)	1000.4 (1131.5; 998.4)	1155.2 (1027.3; 922.6)	1030.9 (1119.4; 960.1)	1135.2 (1177.3; 1102.6)
VLF (ms^2)	849.1 (883.1; 818.7)	781.8 (832.3; 727.8)	900.5 (983.1; 859.9)	861.8 (892.3; 823.8)

HR – heart rate, ShI – shock, HI – heart index, TPVR – total peripheral vascular resistance, HF – high frequency, LF – low frequency, VLF – very low frequency
* the reliability of the differences $p \leq 0.05$ between the types of hemodynamics
# the reliability of the differences $p \leq 0.05$

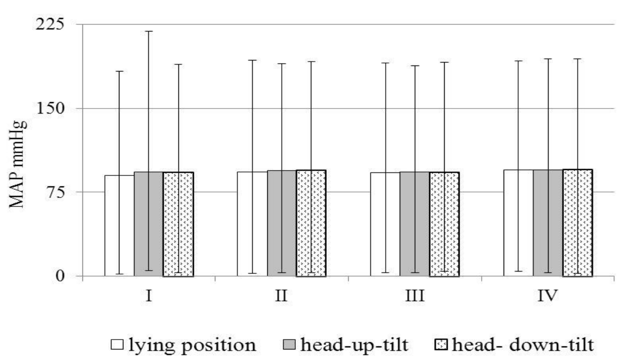


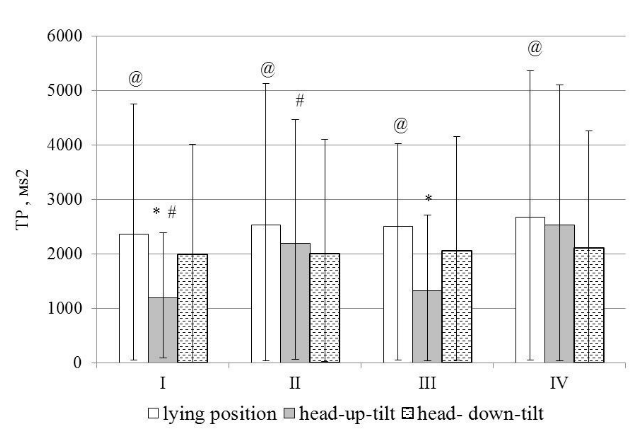
Figure 1. Dynamics of the middle arterial pressure of the studied persons (median, upper and lower quartiles) in the different experimental positions of the body

It is possible that higher values of ShI and HI, and lower TPVR in the surveyed individuals of group 2 as compared with group 1 and persons of group 4 as compared with group 3 may be due to the regulatory peculiarities of their autonomic nervous system. At the same time, the intergroup comparison of the SCHR in the experimental groups under investigation indicated that there were no differences in the regulatory processes of cardiovascular activity under the given conditions ($p \geq 0.05$) (Table 1). It is accepted that the variability of HR is an indicator of the interaction of the body regulatory mechanisms. It is known from literature that the prevalence of intracardiac mechanisms in a lying position is sufficient to optimally ensure the functioning of the CVS at a resting state [10, 26].

The analysis of the quantitative values of MAP in head-up-tilt and head-down-tilt positions did not establish any significant changes in the different surveyed groups ($p \geq 0.05$) (Figure 1). However, the study of other indicators of compensatory reactions to a change of the body position in the space indicated significant changes in the functioning of the CVS. In head-up-tilt conditions, regardless of the type of blood circulation, all of the examined persons showed a decrease of ShI and HI, and an increase of HR and TPVR ($p \leq 0.05$) (Table 2).

Changes in the SCHR in this body position were characterized by a decrease in the power of the HF, LF, and VLF waves ($p \leq 0.05$) in groups 1, 2, and 3, while in group 4, in response to the orthostasis, there was a reliable decrease in the power of the HF and VLF waves and an increase in the power LF ($p \leq 0.05$), indicating differences in the mechanisms of heart regulation in people with different types of CH and physical condition. It is noteworthy that the range of MAP oscillations was the smallest (1–4%), while HR, ShI, HI, and TPVR changed to a greater extent (15–30%).

Consequently, the inclusion of compensatory HR reactions in head-up-tilt position was aimed at maintaining constant blood pressure as the main result of blood circulation regulation under conditions of gravity forces in order to optimize the upper and lower cavernous blood flow to the heart and the mechanisms that provide it [29, 30]. It was found that in both groups of the examined persons with HK and HrK types of blood circulation, during a passive orthopaedic trial, unidirectional compensatory processes were being developed in CH and this was characterized by weakening of the heart capabilities (although within the normal range). A comparison of the indicators of the studied individuals with different types of blood circulation and physical status revealed that there were significantly higher indicators of HI in persons with the HrK type of blood circulation



@ the reliability of the differences $p < 0.05$ relative to the resting state
* between the types of hemodynamics
# in relation to the sportsmen's indicators

Figure 2. Dynamics of the total power of the median spectrogram in the surveyed persons (median, upper and lower quartile) in different experimental positions of the body

Table 2. Indicators of central hemodynamics and cardiac rhythm variability (median, upper and lower quartile) of non-sporting men and athletes with hypokinetic (HK) and hyperkinetic (HrK) types of blood circulation under postural loads

Investigated indicators	Surveyed groups			
	non-sporting men		athletes	
	1 (HK)	2 (HrK)	3 (HK)	4 (HrK)
Head-up-tilt				
HR (bpm)	72.6 (89.3; 67.1)	71.4 (81.4; 64.2)	57.2* (60.9; 52.4)	63.6 (68.3; 60.3)
ShI (ml/m²)	25.1*## (32.3; 22.6)	32.3## (51.1; 43.1)	29.8* (39.4; 29.7)	44.0 (49.6; 40.4)
HI (l/min/m²)	1.8* (2.3; 1.3)	2.3# (3.1; 2.0)	1.7* (2.2; 1.4)	2.8 (3.5; 2.3)
TPVR (din · s · cm⁻⁵/m²)	2.2* (2.7; 1.8)	1.9 (2.2; 1.3)	2.7* (3.0; 2.5)	2.2 (2.6; 1.8)
HF(ms²)	109.2*## (138.1; 89.2)	519.6 (547.2; 503.6)	270.5* (319.7; 237)	500.4 (523.2; 498.6)
LF (ms²)	651.4*## (688.7; 582.9)	1024.7# (1178.2; 963.1)	580.4* (626.4; 529.6)	1350.3 (1382.5; 1317.5)
VLF (ms²)	423.7* (486.5; 397.7)	641.1 (687.4; 609.3)	470.5* (527.6; 503.6)	550.3 (589.4; 512.6)
Head-down-tilt				
HR (bpm)	72.3# (85.6; 78.4)	77.0 (81.3; 71.6)	66.0 (69.4; 61.2)	71.5 (79.8; 69.7)
ShI (ml/m²)	41.6*## (48.9; 37.1)	45.3# (51.9; 41.2)	48.5* (55.3; 43.6)	56.2 (59.1; 51.5)
HI (l/min/m²)	3.0* (3.9; 2.7)	3.5 (3.8; 3.1)	3.2* (3.8; 2.9)	4.0 (4.9; 3.8)
TPVR (din · s · cm⁻⁵/m²)	1.5 (1.8; 0.9)	1.4 (1.9; 1.1)	1.6* (2.0; 1.1)	1.5 (1.9; 1.0)
HF (ms²)	385.1* (409.1; 342.2)	170.3 (231.4; 128.1)	390.7* (427.5; 310.6)	150.3 (181.4; 128.1)
LF (ms²)	722.1*## (781.5; 704.1)	1218.3# (1291.2; 1191.3)	980.1* (1033.7; 926.9)	1408.3 (1461.2; 1381.3)
VLF (ms²)	537.5*## (573.1; 506.2)	612.3 (642.3; 601.5)	985.4* (1019.6; 924.7)	542.37 (592.3; 521.5)

HR – heart rate, ShI – shock, HI – heart index, TPVR – total peripheral vascular resistance, HF – high frequency, LF – low frequency, VLF – very low frequency
* the reliability of the differences $p \leq 0.05$ between the types of hemodynamics
\# the reliability of the differences $p \leq 0.05$
\## $p \leq 0.01$ in relation to sportsmen's indicators

in the head-up-tilt position among non-sporting subjects and sportsmen: by 27.2% and 64.5%, respectively; ShI (by 29.1% and 47.6%); and lower quantitative values of TPVR (by 13.7% and 18.6%) compared with those with the HK type ($p \leq 0.05$). These results draw attention to the fact that such features of CH in representatives of the HrK type of blood circulation can be related to the higher activity of vegetative regulatory centres. It is known that the status of the autonomic nervous system reflects the adaptive reserves of the organism, the degree of stress of the HR regulation mechanisms, or the existence of a CVS pathology [31].

The analysis of the SCHR revealed that the quantitative values of the TP of the median spectrogram in the examined groups 2 and 4 groups from the HrK type were significantly higher compared with those in groups 1 and 3 with the HK type ($p \leq 0.05$) (Figure 2).

In addition, the TP rates of both groups of sportsmen were significantly higher compared with the groups of the non-sporting persons with the similar type of blood circulation ($p \leq 0.05$). It was established that in the conditions of the orthostasis in the surveyed groups with the HK type of blood circulation in relation to the lying position, the reduction of TP occurred in non-athletes and sportsmen, respectively, by 51.2% and 47.3% (Figure 2). Importantly, the dynamics of TP reduction in groups with the HrK type was less intense and equalled 23.6% and 11.2%, respectively, in non-sporting men and sportsmen. The most sensitive SCHR to the orthostasis in all examined participants in group 3, and especially group 1, was VLF, and in people of groups 2 and 4, these were VLF and LF ($p \leq 0.05$).

Discussion

In the surveyed persons with the HK type of blood circulation (both in non-sporting men and athletes), in the head-up-tilt position, MAP was maintained at the expense of a less significant decrease of ShI, respectively in groups 1 and 3 at 23.2% and 21.6%, HI at 10.1% and 10.6%, and at 10.4% and 11.2% increase of TPVR. This was comparable to the subjects with the HrK type of blood circulation, in which the changes of CH were more significant: a decrease in ShI (34.4% and 30.5%), HI (23.4% and 17.7%), and an increase of TPVR by 11.7% and 22.2% ($p \leq 0.05$). In addition, TPVR in the examined athletes of group 4 increased significantly more clearly than in the non-sporting representatives of group 2 with a similar type of blood circulation. In the surveyed groups of persons with the HK type of circulatory system in the examined orthostatic position, the values of HI, ShI, and the lower power of the HF, LF, and VLF spectrum were significantly lower than in the groups with the HrK type ($p \leq 0.05$).

Taking into account that the HrK type of blood circulation was characterized by higher values of HI, ShI, TP, HF, LF, VLF in the orthostatic test conditions and a lower indicator of TPVR compared with the HK type [32, 33], we do not rule out this as a consequence of the higher level of the activity of the regulatory, autonomous, and baroreceptor mechanisms. There are data in the literature proving the less economic mode of heart work in people with the HrK type of blood circulation and their low compensatory properties [10, 23]. In other works, the existence of a smaller shock volume in individuals with the HK type of hemodynamics is emphasized, which in the authors' opinion contributes to the economization of the functions of the heart [32, 34]. The lower values of HI and the main spectral ranges of HF, LF, VLF and the higher value of TPVR, established by us in the orthostasis, are consistent with the data of these researchers [28, 30].

Consequently, orthostasis has a significant effect on the human body and deduces CH from equilibrium. Under such conditions, the CVS is forced to direct all efforts in support of MAP, optimize blood circulation, involving both intra- and extracardiac regulatory mechanisms. In the studied subjects with the HK type of blood circulation in the head-up-tilt conditions, the optimal level of CH was maintained by activating to a lesser extent the vascular and to a greater extent the systemic extracardiac regulation mechanisms. In our opinion, the high degree of stress of the vegetative mechanisms in the surveyed persons with HrK demonstrated the least favourable mode of functioning, a narrow range of compensatory responses, a low threshold of vulnerability to postural loads, along with low adaptive capacity. Maintenance of homeostasis in HrK under these conditions occurred mainly owing to the greater intensity of intracardiac and vascular mechanisms of regulation and less participation of higher vegetative centres.

In head-down-tilt conditions in all surveyed persons, we determined simultaneously raising quantitative values of HI, ShI, and HR, and decreasing the value of TPVR ($p \leq 0.05$) (Table 2). In the wave structure of the HR of the experimental groups in response to the applied gravitational load, a significant decrease was observed in the majority of SCHR and TP ($p \leq 0.05$). At the same time, a number of features were revealed between groups with different types of blood circulation and physical status. The analysis of the quantitative values of TP in the examined groups 2 and 4 in comparison with groups 1 and 2, as well as between similar indices of non-sporting men and sportsmen did not reveal any significant differences ($p \geq 0.05$) (Figure 2). However, the comparison of the dynamics of the TP in response to changing the body position in the space revealed a different intensity of the decreasing. In the examined groups 1 and 3, the decrease of TP was set at 15.6% and 17.6% which was less in comparison with groups 2 and 4, and in groups 2 and 4, the intensity of changes was more pronounced and equalled 20.8% and 21.2%, respectively. A comparison of the reduction of TP indicators in relation to the lying position of sportsmen and non-sporting people pointed to a more significant dynamics of these indicators in athletes.

In groups of people with the HrK type of blood circulation in the head-down-tilt conditions, the spectral characteristics of LF were higher and those of HF lower in comparison with the surveyed persons of the HK type ($p \leq 0.05$). One should notice that during anti-orthostasis, in the examined persons with the HrK type of blood circulation, there was an increase of LF and a decrease of HF, while in groups 1 and 3, under these conditions, a reduction of both components of the cardiac spectrum in relation to the lying position was observed ($p \leq 0.05$). In addition, in the surveyed group 4 as compared with group 2, significantly higher values of LF were detected ($p \leq 0.05$). A larger increase of LF was observed in athletes than in non-sporting men ($p \leq 0.05$). Such differences testify to different mechanisms of heart regulation in people with different types of CH, which are activated under the conditions of anti-orthostasis.

The analysis of the CH indices in the studied individuals with the HrK type revealed a predominance of quantitative values of ShI and HI, and lower values of TPVR, as compared with the subjects with the HK type of blood circulation in the conditions of the head-down-tilt position ($p \leq 0.05$). In the examined persons with the HK type of blood circulation under these conditions, adequate MAP was supported by a more significant increase, both in non-sporting men and in sportsmen, of ShI (by 27.2% and 27.6%, respectively) and HI (by 50.2% and 67.9%), and by a reduction of TPVR (by 25.2% and 33.4%) compared with the changes among the examined persons with the HrK type of blood circulatory activity ($p \leq 0.05$). In the surveyed group of the HrK type of blood circulation, in non-sporting people and sportsmen, we observed a less significant increase of ShI (by 8.1% and 11.7%, respectively) and HI (by 16.6% and 17.6%), and a decrease of TPVR (by 11.8% and 16.7%) ($p \leq 0.05$).

Such results confirm the leading role of vegetative regulatory mechanisms of the hemodynamics in the examined persons with HrK, and of intracardiac and vascular mechanisms in the subjects with the HK type of blood circulation under conditions of passive anti-orthostasis. Probably, the absence of the differences in the values of MAP in the surveyed persons with different types of blood circulation ($p \geq 0.05$) under these conditions was maintained owing to the unequal participation of the cardiac and vasomotor components. According to our data, the optimum value of MAP for the position of head-down-tilt in the persons with the HrK type of blood circulation was provided mainly by high cardiac output, lower TPVR, and higher activity of LF and lower HF. In the participants with the HK type of blood circulation, MAP was supported by a greater activity of the parasympathetic regulation channel of HR and TPVR.

Importantly, there was a significantly lower ShI ($p \leq 0.05$) and a slightly longer duration of R-R intervals in the examined individuals of groups 1 and 3 with the HK type of blood circulation compared with the studied groups 2 and 4 with the HrK type of blood circulation under conditions of anti-orthostasis. As it is known, the compensating reactions of the heart are manifested in several ways, such as tachycardia, dilatation, hypertrophy, aimed at creating the corresponding minute volume of blood in accordance with the conditions of existence. However, as our studies show, each type of central hemodynamics to achieve the maximum effectiveness of the CVS used its own version of the ratio of these compensatory techniques. The applied correlation analysis confirmed the interdependence between HR and blood flow to the ventricles (in the examined persons with HK and HrK, respectively, $r = 0.56$ and $r = 0.63$, $p \leq 0.05$–0.01). In the participants with the same type of blood circulation, namely, in persons of group 4 in comparison with groups 2 and 3, in relation to group 1, the economization and rationalization of the heart function was determined by increasing the strength of cardiac contractions (a positive inotropic effect), as evidenced by the significantly higher ShI ($p \leq 0.05$). It is possible that this was facilitated by the best physical state of the body of the sportsmen. In the examined group 2 relative to group 1, a higher HR was detected, which increased myocardial tension and energy expenditure, decompensating and exhausting the reserve capabilities of the adaptive mechanisms. It is known from the literature that people with the HrK type of blood circulation and high HR have a higher probability of arrhythmias, myocardial infarction, hypertension [9, 10], which indicates the need to take into account not only the initial data of the type of blood circulation and the wave structure of the HR, but also the reactivity of the CVS on the effect of gravitational loads. The results of our research show that the direction of compensatory reactions had a clear dependence primarily on the type of blood circulation, as well as on the physical status of the surveyed persons.

The comparison of the CVS indicators in the study participants in the head-down-tilt position indicated the involvement of excellent mechanisms of HR regulation in the individuals with different types of central hemodynamics. Persons with the HK type of blood circulation, unlike HrK, under these conditions demonstrated the achievement of the optimal CH level by lower activation of the contractile function of the heart and extracardiac mechanisms of regulation, while the those with the HrK type of blood circulation had more control from the central nervous system against the backdrop of the strain of self-regulation processes. A narrowed range of compensatory responses, a low threshold of vulnerability, and a high degree of stress in the vegetative mechanisms in HrK indicate lower energy possibilities of the heart. It is known that a vagosympathetic dissonance is the reason for a shift in the work of the heart [10, 15, 31]. We maintain that in people with the HrK type of blood circulation, there is a high degree of risk of cardiovascular complications due to the high activation of the regulatory and autonomous mechanisms and a higher level of their stress in the conditions of our postural loads, which makes them the least adaptive.

Limitations

The presented study has some limitations. It was performed among healthy men aged 18–21 years, athletes and non-sportsmen. The methods of CH and SCHR were applied, which could have influenced the outcomes.

Conclusions

1. The differences in the compensatory reactions of CH and SCHR of men with different types of blood circulation and physical status of the organism were established in the conditions of postural loads.

2. For the adaptive response of the CH in persons with the HrK type, under the condition of moving the body to the head-up-tilt position, more intentional participation of the intracardiac and vascular and less participation of the higher vegetative centres was characteristic. In the surveyed individuals with the HK type of blood circulation, the optimal level of CH was maintained by activating to a smaller extent the vascular and to a greater extent the systemic extracardiac regulation mechanisms.

3. In conditions of passive movement of the body to the head-down-tilt position, the compensatory reactions of the CH of the participants with the HK type of blood circulation, especially sportsmen, were characterized less by the activation of the contractile functions of the heart and the extracardial mechanisms of regulation, and hyperkinetics typically involved to a greater extent the higher regulatory centres of the central nervous system in the background of the tension of the self-regulation processes.

4. The revealed features of the CH and HR regulation mechanisms can be useful in the field of clinical and sports medicine, physical rehabilitation, professional orientation and selection.

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Conflict of interest

The authors state no conflict of interest.

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