Features of immediate adaptation of the circulatory system to static load in persons with different body mass index
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Introduction
In 2020, 100 years have passed since Lingard discovered the phenomenon of static effort. The deep nature of the phenomenon named after the discoverer was also studied by physiologists in the following decades. However, sports physiologists pay much more attention to physical exercises of a dynamic nature [3, 14]. In the vast majority of sports, muscle activity is dynamic in nature, but recently there has been a growing interest in health physical culture in static exercises [5, 15], to the study of which a significant contribution was made by the domestic scientist O. R. Radzievsky. They are an effective tool not only for developing strength, but also for endurance and flexibility. In strength fitness, programs have been developed based on the use of static exercises for body weight correction, etc. [2, 10, 12, 13, 18, 24]. However, we should note that there are still relatively few special works aimed at researching the impact of static loads on the parameters of the blood circulation system in modern scientific development [6, 11, 16]. The question of the relationship between static physical load and
anthropometric parameters attracts even less attention of researchers [1, 14]. We could not find scientific publications devoted to the study of the influence of body composition on the course of short-term adaptation to dosed static load in the available literature.

The purpose of our work was to study the effect of dosed static load on the parameters of the circulatory system during the early recovery period in people with different body mass indexes.

Materials and methods

The work is a fragment of the research work of the department of medical and biological disciplines of the National University of Physical Education and Sports of Ukraine “The influence of exogenous and endogenous factors on the course of adaptive reactions of the body to physical exertion of various intensities” (state registration number 012U108187). 42 untrained young men (20 years old) who had no bad habits, were practically healthy and had no acute diseases or chronic pathology were examined. Martine’s test was used for preliminary selection and formation of groups. For the next stage of work, from the total number of examined persons, those in whom the reaction to the Martine test was normotonic (36 persons) were selected. In the future, to study the reaction of the circulatory system to static load, body weight and length were determined (using a floor height meter with mechanical scales RPV 2000), body mass index (BMI) according to the Quetelet formula, (the Quetelet index, Ql = body weight(kg)/height²(cm), maximum standing strength (using a standing dynamometer DS-200). For further analysis of the obtained results, the examined young men were divided into 2 groups according to the BMI criterion in accordance with WHO recommendations - persons with a normal BMI (nBMI group, n=18, young men with BMI from 18.8 to 24.9; group mean - 21.6), individuals with increased BMI (iBMI, n=18, examined with BMI from 27.4 to 30.0; group mean - 28.1). Individuals with BMI below the norm, and with a BMI considered as obesity, there were no subjects examined in our study.

The Bioethics Committee of the National University of Physical Education and Sports of Ukraine (protocol № 3 dated 22.01.2021) established that the research does not contradict the basic bioethical standards of the Helsinki Declaration, the Council of Europe Convention on Human Rights and Biomedicine (1977), the relevant WHO resolutions and the laws of Ukraine.

Static load (SL) was modeled by holding on a static dynamometer DS-200 for 15 seconds a force that was 50 % of the maximum static force. Before and at the 1st, 2nd and 3rd minutes after the end of the exercise, blood pressure was measured in a standing position (according to the Korotkov method), heart rate was counted for 10 seconds by palpation on the left carotid artery. At the same time, a tetrapolar thoracic rheoplethysmogram was recorded in a standing position using the computerized diagnostic complex "Cardio+". The following parameters were analyzed - heart rate (HR), stroke and minute blood volumes (SV and MBV, respectively), stroke and cardiac indices (SI and CI, respectively), total peripheral vascular resistance (TPR), systolic and diastolic blood pressure (sAT and dAT, respectively). We analyzed the pumping function of the heart and the state of peripheral resistance of blood vessels by indicators normalized to the body surface area of the examinees (SI, CI), and not by the absolute values of systolic and cardiac output and TPR, with the aim of leveling anthropometric differences between individuals from different groups.

Statistical data processing was carried out using the computer program IBM SPSS Statistics (version 26), using non-parametric methods of evaluating the obtained research results.

Results

A total of 36 young men were examined, the height of the subjects was in the range of 170-193 cm (average height - 179.8 cm), body weight - in the range of 60-103 kg (average value - 78.4 kg), BMI - from 19.8 to 28.9 (on average - 24.2). Changes in central hemodynamic parameters in examined young men with different body mass indexes before static exercise and in the early recovery period after it are presented in Table 1.

At rest, the heart rate in individuals of the nBMI group (76.01±3.12 beats/min) is significantly lower by 10.27 % compared to representatives of the iBMI group (83.82±3.42 beats/min). Static load causes an initial decrease in heart rate in individuals of both groups (by 6.14 % and 8.11 %, all with p<0.05) compared to the initial state. However, already 1 minute after the end of the load, the heart rate increases in young men of both groups, but to a different extent - by 5.01 % in the nBMI group, and by 7.48 % in the iBMI group (all with p<0.05). In the future, a tendency to restore the initial level of heart rate was recorded. This was more effective in young men with a normal BMI, because at the last follow-up period, the difference in heart rate with resting state was 1.46 % in them, while in individuals from the iBMI group it was 3.23 %.

The value of SV in individuals of the nBMI group at rest was 66.70±2.89 ml/min, which is 15.10 % higher than the value of SV in the iBMI group (56.63±2.67 ml/min). Changes in the value of SV after static loading are characterized by similar dynamics in individuals of both groups - immediately after SL, the SV parameter decreases, and after one minute it increases compensatory, followed by a gradual recovery to the initial state. Thus, the initial decrease in SV immediately after SL was 6.43 % (p<0.05) in the nBMI group, and 9.57 % (p<0.05) in the iBMI group. After 1 min. after the cessation of exercise, a compensatory increase in SV occurs in individuals of both groups - by 14.20 % (p<0.05) in the nBMI group and by 19.83 % (p<0.05) in the iBMI group. As in the case of heart rate changes, the SV parameter recovered faster in individuals of the nBMI group because, at the end of
the observation period, the SV difference with the initial state was 3.81 % in them, in contrast to the iBMI group, in which the SV differed by 4.03 %.

The value of the MBV parameter in the nBMI group at rest was 5.071±0.362 l/min, which is statistically significantly higher than the MBV value in the iBMI group (4.753±0.291 l/min) by 6.37 %. Static loading with respect to changes in MBV causes the same dynamics as in the case of HR and SV. Thus, in the first minute after SL, a decrease in MBV was recorded in both groups, but to a different extent - in the nBMI group by 12.81 % (p<0.05), in the iBMI group by 16.91 % (p<0.05). The second minute after the load is characterized by a compensatory increase in MBV, which changes the initial decrease of this parameter immediately after SL. In the nBMI group, the degree of growth was 19.92 % (p<0.05), whereas in the iBMI group it was 28.79 % (p<0.05). The third minute after exercise is characterized by a gradual recovery of the MBV value in both groups, but to a different extent - more effectively in individuals with a normal BMI (the difference with the resting state was 5.32 %, while in the iBMI group it was 7.39 % (p<0.05).

The value of SI in the nBMI group at baseline was 36.05±1.42 ml/m², which is 19.86 % higher than the value of the same parameter in the iBMI group (28.89±1.21 ml/m²). The first minute after SL is characterized by a decrease in SI in both groups - by 6.43 % (p<0.05) in the nBMI group, and by 9.57 % (p<0.05) in the iBMI group. The second minute after SL is characterized by a compensatory significant increase in SI values in both groups - in the nBMI group by 14.20 % (p<0.05), in the iBMI group by 19.83 % (p<0.05). Just as in the case of changes in heart rate, SV and MBV, the third minute after exercise is characterized by the recovery of the value of SI to the values of the resting state, but this happens faster in individuals of the nBMI group - in them by 3 minutes. after SL, the difference with the resting state is 3.81 %, while in the iBMI group it is 4.03 %.

The value of the cardiac index in individuals of the nBMI group at rest is 2.742±0.228 l/min/m², which is 11.63 % higher than the similar parameter in the iBMI group (2.421±0.174 l/min/m²). Static load causes a decrease in the CI parameter, which was recorded in the first minute after the end of SL in both groups - by 12.18 % (p<0.05) in the nBMI group, and by 16.91 % (p<0.05) in the iBMI group. The second minute after SL is characterized by a compensatory increase at the level of 19.92 % (p<0.05) in individuals with normal BMI, and by 28.79 % (p<0.05) in the iBMI group. The course of the third minute after static loading is characterized by a decrease in CI, but reaching the value of the initial state does not occur in any of the groups. However, it is more effective to restore CI in the nBMI group because the difference with the resting state in them is 3 min is 5.32 %, and in the iBMI group - 7.39 %. At all follow-up periods, the value of CI in individuals from the nBMI group was statistically significantly greater than that in individuals from the iBMI group.

The value of TPR in persons with a normal BMI is 1421±98 dynes/sec/cm -5, which is 8.97 % less than the value of the same parameter in the iBMI group (1549±104 dynes/sec/cm -5). Static load leads to the opposite changes compared to previously considered parameters - there is a strong increase in TPR in both groups, to a lesser extent - in the nBMI group (by 31.64 %, p<0.05), to a greater

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
<th>Before SL</th>
<th>First minute after SL</th>
<th>Second minute after SL</th>
<th>Third minute after SL</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR, beats/s</td>
<td>nBMI</td>
<td>76.01±3.12</td>
<td>71.34±3.01*</td>
<td>79.82±3.23*</td>
<td>77.12±3.09</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>83.82±3.42*</td>
<td>70.02±3.38**</td>
<td>90.09±3.55**</td>
<td>66.53±3.41*</td>
</tr>
<tr>
<td>SV, ml</td>
<td>nBMI</td>
<td>66.70±2.89</td>
<td>62.41±2.32*</td>
<td>76.17±3.31*</td>
<td>69.24±2.91</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>56.63±2.67**</td>
<td>51.21±2.81**</td>
<td>67.86±2.81**</td>
<td>58.91±2.85</td>
</tr>
<tr>
<td>MBV, l/min</td>
<td>nBMI</td>
<td>5.071±0.362</td>
<td>4.452±0.314*</td>
<td>6.082±0.411*</td>
<td>5.344±0.381</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>4.753±0.291*</td>
<td>3.942±0.191**</td>
<td>5.926±0.394**</td>
<td>5.102±0.364**</td>
</tr>
<tr>
<td>Sl, ml/m²</td>
<td>nBMI</td>
<td>36.05±1.42</td>
<td>33.74±1.20*</td>
<td>41.17±1.73*</td>
<td>37.43±1.50</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>28.89±1.21*</td>
<td>26.13±1.11**</td>
<td>34.62±1.40*</td>
<td>30.06±1.35*</td>
</tr>
<tr>
<td>Cl, l/min/m²</td>
<td>nBMI</td>
<td>2.742±0.228</td>
<td>2.418±0.215*</td>
<td>3.291±0.262*</td>
<td>2.890±0.233</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>2.421±0.174**</td>
<td>2.017±0.153**</td>
<td>3.125±0.213**</td>
<td>2.601±0.187**</td>
</tr>
<tr>
<td>TPR, dynes/sec/cm -5</td>
<td>nBMI</td>
<td>1421±98</td>
<td>1871±114*</td>
<td>1302±109*</td>
<td>1391±102</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>1549±104**</td>
<td>2205±183**</td>
<td>1329±121*</td>
<td>1519±142*</td>
</tr>
<tr>
<td>sAT, mmHg.</td>
<td>nBMI</td>
<td>120.0±2.3</td>
<td>136.3±4.7*</td>
<td>132.9±3.8*</td>
<td>123.7±2.6</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>122.4±3.4</td>
<td>141.9±4.8*</td>
<td>134.7±4.0*</td>
<td>126.9±2.8</td>
</tr>
<tr>
<td>dAT, mmHg.</td>
<td>nBMI</td>
<td>75.14±2.01</td>
<td>88.00±3.14*</td>
<td>82.00±0.02*</td>
<td>77.45±2.76</td>
</tr>
<tr>
<td></td>
<td>iBMI</td>
<td>77.25±2.45</td>
<td>92.00±4.05*</td>
<td>84.88±3.92*</td>
<td>81.88±3.51</td>
</tr>
</tbody>
</table>

Notes: * - statistically significant compared to resting state, ^ - statistically different from the values of the nBMI group in the same observation period.
The values of systolic and diastolic pressure at rest in the individuals of both groups are not statistically significantly different. The dynamics of sAT and dAT in both groups in response to static load are very similar - the values of both types of pressure immediately after SL increase (to a greater extent in individuals from the iBMI group), gradually return to resting values in later periods. However, the degree of initial increase in sAT and dAT immediately after SL is greater in the iBMI group. The restoration of the initial value of sAT and dAT occurs more efficiently in the nBMI group because the percentage of deviation of the values of both types of pressure at 3 minutes after SL in individuals with a normal BMI is smaller compared to the iBMI group.

Discussion

According to the data of our study, the parameters of central hemodynamics are characterized by a number of differences depending on BMI and differ in individuals of different groups both in a state of rest and in the nature of urgent adaptation to static load. At rest, heart rate in both groups met the criteria for normocardia, but in the iBMI group it was significantly higher than in the nBMI group. The value of MBV in the initial state in individuals with a normal BMI exceeded the value of the similar parameter in the iBMI group due to a higher value of SV. Such a conclusion can be made in view of the lower value of the HR parameter in persons with a normal BMI compared to young men in whom the BMI is elevated. They also have higher parameters of the cardiac and shock indices at rest compared to individuals of the iBMI group. Against the background of higher values of SV and MBV in young men with a normal BMI, this may be evidence of higher functional reserves of the heart and a greater level of tolerance to physical exertion (in particular, static) compared to individuals with an increased BMI. Values of both measured types of blood pressure in the initial state did not have a statistically significant difference between the groups. However, the values of both types of pressure were more significant in young men with increased BMI both at rest and at all times after static exercise, which is consistent with the data of other researchers [17]. The greater value of total peripheral resistance in individuals from the iBMI group indicates an increased tone of pre- and post-capillary resistance vessels, which is most likely caused by increased basal sympathetic influences [19, 22].

Static load causes the same nature of changes in the parameters of the circulatory system, regardless of BMI; the difference in BMI determined only the degree of manifestation of one or another reaction of the cardiovascular system. The initial decrease in HR, SV, and MBV values immediately after SL, present in both groups, is a strain effect. It is caused by maintaining a powerful tonic effort, increasing intrathoracic, intrapulmonary pressure, and as a result, increasing compression on the heart [5, 6]. Under conditions of compression of blood vessels inside skeletal muscles during static effort, the volume of venous return of blood to the heart decreases [4, 20, 21]. As a result of the implementation of myogenic mechanisms of heart activity, this leads to a decrease in the value of the main parameters of its work, which was recorded by us immediately after SL. Further growth of the pumping function of the heart in individuals of both groups has a compensatory nature and is characterized by the desire to restore blood circulation in vessels that were compressed during static stress [7, 25]. The increase in both types of blood pressure under the influence of SL can be explained by the increase in pressure inside the aorta during the maintenance of static tension, which, according to the logic of the Anrep phenomenon (loading the heart with outflow), leads to an increase in the force of heart contraction, and as a result - to an increase in the value of sAT and dAT [8, 9].

Taking into account the greater degree of reactivity of the circulatory system in the early period of adaptation to static load in individuals with increased BMI, as well as the fact that at the last follow-up period the difference between the values of the measured parameters was smaller in the nBMI group, it can be argued that a more balanced and effective course of recovery after SL occurred in individuals with a normal body mass index.

Summarizing all of the above, it is worth noting that a greater degree of manifestation of the Lingard phenomenon in our study was recorded in young men with an increased body mass index. It can be assumed that this is connected with an increased volume of circulating blood, a greater load on the heart and stronger sympathetic influences on the activity of the heart and blood vessels. In our opinion, for more detailed conclusions, the study of changes in central hemodynamics during static exercise depending on BMI should be supplemented by the study of the reaction of the circulatory system to SL with mandatory consideration of fat and muscle components in the body composition. This will open the possibility to more accurately reveal the deep mechanisms of differences in the reactions of central hemodynamics of persons with different BMIs to different regimes of physical exertion.

Conclusion

1. At rest, young men with a normal body mass index differ from persons with an increased body mass index by a lower heart rate, total peripheral resistance and blood pressure, as well as by higher values of stroke and minute blood volumes, stroke and heart indices.
2. The dosed static load leads to the same nature of changes in the parameters of the circulatory system in all
examined persons, regardless of the body mass index. Differences in body mass index affect only the degree of manifestation of certain changes.

3. A more significant manifestation of the Lingard phenomenon was recorded in young men with an increased body mass index, as evidenced by a greater degree of deviation of the measured parameters of the circulatory system in response to static load.

4. The results obtained by us allow us to predict the reaction of the circulatory system to static load depending on the value of the body mass index, which can be of practical importance during strength training.

References


Features of immediate adaptation of the circulatory system to static load in persons with different body mass index

**OSOBLIVOSTI TERYNOVOI ADAPTACI SISTEMI KROVOOBIGU DO STATICHNOGO NAVANTAJENIY V OSIB Z RIZNIM INDEXOM MASY TILA**


In the overwhelming majority of sports, muscular activity is characterized by dynamic nature, but recently, sports physiologists pay significant attention to static exercises. Deep mechanisms of the phenomenon of static strain are studied since its disclosure, but to date, there is a lot of gaps in biological knowledge regarding the impact of static load on the parameters of the function of the circulatory system in individuals with different anthropometric characteristics. The aim of the work - study the impact of dosed static load on the parameters of the circulatory system in the period of early recovery in persons with different body mass index. During the study, 36 boys were examined, whose criterion body mass index (BMI) was divided into two groups - boys with normal BMI (group nBMI, average BMI value in the group - 21.6), and boys with increased BMI (group pBMI, average BMI value in the group - 28.1). Static load (SL) was modeled by maintaining on the static dynamometer DS-200 for 15 seconds of an effort, which constituted 50% of the maximum static force. Before the load and 3 minutes after its completion, the basic parameters of central hemodynamics were measured in the examined persons using tetrapolar chest plethysmography on a computer diagnostic complex "Cardio+" (Ukraine). The statistical processing of the obtained data was performed using the IBM SPSS Statistics (version 26), with the use of non-parametric methods to estimate the obtained results. We established that in the initial state, boys with a normal body mass index differed from persons with an increased body mass index by a smaller number of heartbeats, general peripheral resistance and arterial pressure, as well as greater values of stroke and minute volumes of blood, stroke and cardiac indexes. Dosed static load leads to similar changes in the parameters of the circulatory system in all examined persons, regardless of the body mass index. Differences in the body mass index influence only the degree of manifestation of certain changes. More pronounced manifestation of the phenomenon of Linagar was recorded in boys with an increased body mass index, which is evidenced by a greater deviation of measured parameters of the circulatory system in response to static load.

**Key words:** circulatory system, early recovery, static load.