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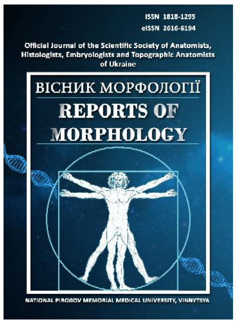

Features of functional changes in blood vessels during the period of early recovery after static physical exercise

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The cardiovascular system is one of the leading functional systems of the body, which ensure and maintain the proper level of physical performance of the body during physical exertion. Bodybuilding is one of the areas of sports activity in which taking into account the individual characteristics of the adaptation of the circulatory system to powerful muscle work of significant intensity is decisive for building an optimal training regimen. Anatomical and physiological remodeling of the heart as a result of regular sports leads to changes in the pumping function of the myocardium, as well as indicators of central and peripheral hemodynamics. Currently, there is a problem of insufficient study of the functional changes of blood vessels in response to a static regime of physical exertion in the early post-workout period. The purpose of the research is to study the characteristics of the reaction of blood vessels during the early recovery period after dosed physical exertion of a static nature. During the study, 34 young men were examined in the following groups: 1 group - persons engaged in bodybuilding; 2 group - young men engaged in fitness; 3 group - untrained persons. Maximum arbitrary static force was determined in all examined persons using a static dynamometer DS-500, static load was modeled by holding on a static dynamometer for 30 seconds an effort corresponding to 50 % of the maximum static force. Functional changes of blood vessels and central hemodynamics were registered by the method of tetrapolar thoracic impedance rheoplethysmography using the computerized diagnostic complex "Cardio+" (Ukraine). Statistical data processing was carried out using the computer program IBM SPSS Statistics (version 26), using non-parametric methods of evaluating the obtained results. It was established that static exercise in young bodybuilders leads to an increase in minute blood volume due to optimal physiological changes in central hemodynamic parameters. In persons engaged in fitness and in untrained young men, the minute volume of blood decreases and circulation conditions deteriorate immediately after exercise, which complicates the processes of rapid recovery after physical exercise in a static mode. A decrease in vascular resistance to blood flow with a simultaneous increase in minute blood volume was revealed immediately after static exercise in young bodybuilders compared to individuals engaged in fitness and untrained individuals. It was established that the circulatory system of young bodybuilders is most optimally adapted to static loads compared to persons engaged in fitness and untrained young men.

Keywords: *blood vessels, central hemodynamics, static load.*

Introduction

The cardiovascular system (CVS) is one of the most important functional systems of the body, which determine and limit the physical performance of an athlete's body [9, 10, 27]. Adaptation of the components of the circulatory system to different modes of physical exertion is one of the central issues of biological and sports science due to the fact that the reduced adaptive capabilities of the specified system limit the realization of the functional reserves of the athlete's body during various types of physical exertion [19, 22, 28]. Bodybuilding, as one of the directions of health-improving motor activity, is characterized by a significant intensity and volume of training loads [11, 26]. Without proper consideration of the individual characteristics of the adaptation of the circulatory system to powerful muscle work, this can lead to pre-pathological, and sometimes even to pathological changes in the activity of the heart and blood vessels [18, 24], which, with suboptimal physical exertion, can lead to deaths during sports [6, 20].

Regular physical exertion during bodybuilding classes leads to the occurrence of specific changes in the circulatory system. Morphological and functional remodeling of the sports heart is accompanied by changes in the pumping capacity of the myocardium, as well as indicators of central and peripheral hemodynamics [8, 15, 25]. Bodybuilding as a sport with a highly static component of muscle exercises is characterized by an insufficient study of the problems of functional changes in blood vessels in response to a static mode of physical exertion and actualizes the appearance of detailed studies of the impact of loads on the indicators of the circulatory system.

The purpose of our study was to study the characteristics of the reaction of blood vessels during the early recovery period after dosed physical exertion of a static nature.

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). Practically healthy young men (21 years old) without bad habits took part in the study. Examination of young men was carried out in the morning, after at least 15 minutes of passive rest after arriving at the laboratory. The research was conducted in two stages. At the first stage, in order to determine the type of reaction of the circulatory system to physical exertion, representatives of all groups were subjected to a modified Martine functional test (a test with 20 squats for 30 seconds). Only persons with a normotonic type of response of the circulatory system to stress were admitted to further research. In total, 34 such persons took part in the study, who were divided into 3 groups: 1 group - persons engaged in bodybuilding; 2 group - young men engaged in fitness; 3 group - untrained persons.

The Bioethics Committee of the National University of Physical Education and Sports of Ukraine (protocol No. 2 dated 16.12.2020) 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), relevant WHO resolutions and laws of Ukraine.

At the second stage of the study, the reaction of the circulatory system to the dosed static load (SL) was determined. The maximum voluntary static force was determined in all persons involved in the examination using a static dynamometer DS-500. Static load was modeled by holding on a static dynamometer for 30 seconds a force corresponding to 50% of the maximum static force. Functional changes of blood vessels and central hemodynamics were registered by the method of tetrapolar thoracic impedance rheoplethysmography using the computerized diagnostic complex "Cardio+" (Ukraine). The following indicators of hemodynamics were evaluated - minute blood volume (MBV), specific peripheral resistance (SPR), total peripheral resistance (TPR), dicrotic index (DicIn), diastolic index (DiaIn), tone of all arteries (TAA), tone of large arteries caliber (TLAC), tone of medium and small caliber arteries (TMSAC). The indicated indicators were recorded before the load, immediately after the load, as well as 1, 2 and 3 minutes after the load.

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

Table 1 presents the dynamics of the reaction of the blood vessels of the examined persons to a static load and in the early period of recovery after it.

In the initial state, young men engaged in bodybuilding differ from representatives of groups 2 and 3 in significantly lower parameters of SPR and TPR, DisIn and DiaIn, as well as reduced tone of arterial vessels of all calibers ($p<0.05$). The MBV parameter in bodybuilders at rest significantly exceeds the value of the similar indicator in young men engaged in fitness by 13.6%, and by 24.8% the similar parameter in untrained individuals (all with $p<0.05$).

Untrained individuals, on the contrary, are characterized by the largest values of all the hemodynamic parameters we studied, except for the MBV parameter, which is the smallest compared to the values of the other groups. Indicators of functioning of blood vessels of young men engaged in fitness in the initial state are characterized by intermediate values compared to individuals from groups 1 and 3.

After static loading, there is a significant increase in MBV in young bodybuilders both immediately after SL (by 6.9%, $p<0.05$) and 1 minute after it (by 30.2%, $p<0.05$). In contrast to them, the determined indicator of representatives of groups 2 and 3 immediately after SL decreases by 24.5% and 13.1%, respectively ($p<0.05$). However, 1 min after exercise, a significant increase in minute blood volume was observed by 22.9% (group 2, $p<0.05$) and 22.1% (group 3, $p<0.05$). Further observation periods (2 and 3 min after SL) were characterized by a gradual return of the MBV value to the initial state.

Immediately after SL, representatives of all groups observed an increase in SPR, the least expressed in bodybuilders (by 1.5%) compared to individuals engaged in fitness, in which the degree of increase in SPR was 33.6% ($p<0.05$). An increase in the specified parameter by 30.5% ($p<0.05$) was registered in untrained young men. However, already 1 min after the static load, the SPR parameter significantly and reliably decreases in all examined persons - by 21.6% (group 1), 7.9% (group 2), 6.1% (group 3) compared to the initial state. After 2 and 3 min after SL, the SPR index gradually returned to initial values in all examined

Table 1. Changes in indicators of the functioning of blood vessels during the period of early recovery after static exercise.

Parameter	Group	Before SL	Immediately after SL	1 minute after SL	2 minutes after SL	3 minutes after SL
MBV	1	6.484±0.391	6.930±0.340*	8.435±0.380*	7.470±0.340*	6.536±0.390
	2	5.604±0.680^	4.757±0.472^*	6.883±0.710^*	6.330±0.463^*	5.825±0.494^
	3	4.874±0.364^#	4.232±0.270^#*	5.948±0.341^#*	5.476±0.352^#*	5.038±0.330^#
SPR	1	27.69±3.65	28.09±3.22	21.68±2.54*	24.16±2.85*	27.46±3.38
	2	31.39±2.38^	42.30±4.18^*	28.18±3.57^*	29.14±2.63	30.39±2.13^
	3	37.21±6.48^#	50.78±7.31^#*	34.42±5.23^#*	35.53±5.92	36.77±6.12^#
TPR	1	1128±89	1146±76	884.4±51.9*	984.3±52.8*	1119±78
	2	1312±46^	1769±87^*	1175±71^*	1218±43^*	1272±38^
	3	1475±176^#	2034±124^#*	1378±129^#*	1420±114^#	1470±134^#
DicIn	1	48.23±1.85	42.14±1.65*	44.26±1.75*	46.24±1.75	48.10±1.80
	2	55.52±1.79^	69.22±2.09^*	50.72±1.93^*	52.91±2.03^*	55.24±1.97^
	3	60.83±1.89^#	72.38±1.89^#*	55.75±2.03^#*	57.76±1.98^#*	60.03±1.78^#
DiaIn	1	50.61±1.27	45.59±1.41*	47.12±1.41*	48.82±1.51*	50.44±1.23
	2	55.02±2.02^	61.19±1.82^*	58.83±1.62^*	57.23±1.59	55.73±1.84^
	3	60.44±1.74^#	66.71±1.82^#*	64.81±1.35#*	62.84±1.25^#	61.41±1.43^#
TAA	1	19.67±0.35	21.08±0.73*	18.81±0.35*	19.25±0.25	19.64±0.37
	2	22.32±1.60^	27.10±1.18^*	19.51±1.94^*	20.78±1.97^*	21.98±1.67^
	3	27.05±2.76^#	30.43±3.04^#*	25.27±3.17^#	26.12±2.31^#	26.98±2.59^#
TLAC	1	6.868±0.179	7.548±0.278*	7.335±0.216*	7.127±0.176	6.918±0.181
	2	8.123±0.319^	9.457±0.241^*	9.172±0.295^*	8.776±0.278^*	8.364±0.408^
	3	10.36±0.48^#	11.60±0.39^#*	11.31±0.29^#	10.99±0.39^#	10.62±0.52^#
TMSAC	1	11.83±0.48	11.24±0.46*	11.50±0.49	11.63±0.48	11.77±0.48
	2	14.07±0.96^	17.24±0.86^*	12.30±0.34^*	13.15±0.31	13.81±0.92^
	3	16.64±0.78^#	19.39±0.93^#*	15.02±0.48^#*	15.70±0.69^#	16.08±0.80^#

Notes: here and hereafter, * - p<0,05 compared to the value before the static load of its own group; ^ - p<0,05 compared to the similar indicator of 1st group; # - p<0,05 compared to the similar indicator of the 2nd group.

young men. A similar trend characterizes the parameter of total peripheral resistance, which also increased immediately after SL in different ways - it almost did not change in bodybuilders (the degree of unreliable growth was 1.7%), it increased most significantly in people of group 2 (by 34.8%, p<0.05) and untrained young men (by 30.3%, p<0.05). After the specified initial increase, a decrease in TPR was observed in all examined persons - by 21.6% in group 1, by 10.5% in group 2, by 6.3% in group 3 (all with p<0.05).

Changes in DicIn have a slightly different character between the representatives of group 1 and the other examinees - in bodybuilders it decreases by 12.7% immediately after SL with a gradual return to initial values 3 min after exercise. In contrast, in representatives of groups 2 and 3, DisIn increased sharply immediately after SL - by 24.7% (group 2, p<0.05) and by 19.1% (group 3, p<0.05). In the subsequent periods of observation, DisIn in these individuals gradually decreased to baseline values.

A similar trend characterizes the dynamics of the DiaIn parameter. In the group of bodybuilders, after an initial decrease of 9.3% (p<0.05) immediately after SL, a gradual return of DiaIn to baseline values is observed. An increase in the specified parameter by 11.3% and 10.4%, respectively (all with p<0.05), was registered in persons engaged in fitness and untrained young men, with a further return to normal 3 min after SL.

The tone of all arterial vessels immediately after exercise in all examined persons changes in the same direction - immediately after SL it increases to a different extent depending on the group, then decreases to the initial values. Thus, the specified parameter increases by 7.1% in people of group 1, by 21.5% in group 2, and by 12.2% in group 3 (all with p<0.05). The tone of large-caliber arteries also shows a similar trend of changes - immediately after SL it increases to varying degrees (by 9.9% in individuals of group 1, by 16.4% in young men of group 2, by 12.0% in individuals of group 3, all - p<0.05).

Some distinctive features distinguish the dynamics of the tone of the arteries of small and medium caliber, which in the group of bodybuilders immediately after SL decreases by 5.0%, then gradually returns to the initial value. In contrast, in individuals of groups 2 and 3, there is a significant increase in the tone of small and medium-sized arteries (by 21.9% and 16.5%, respectively, $p<0.05$), which already 1 minute after SL is replaced by a similar sharp decrease in tone (by 12.8 % in the 2nd group and by 9.6% in the 3rd group, $p<0.05$). In the subsequent periods of observation, the return of the tone to the initial values was registered.

Discussion

In the initial state, representatives of group 1 are characterized by lower values of SPR and TPR, which indicates a reduced tone of pre- and postcapillary resistance vessels in bodybuilders compared to untrained individuals and young people engaged in fitness. This is confirmed by lower values of the dicrotic index, which characterizes the tone of the vessels of the precapillary bed, as well as the diastolic index, which depends on the tone of the postcapillary vessels, compared to groups 2 and 3. It should be noted that before exercise, the tone of small, medium and large arterial vessels in bodybuilders is also statistically significantly lower compared to untrained young men and those engaged in fitness. All of the above indicates that the blood vessels of bodybuilders at rest are characterized by a lower tone of the smooth muscles of the walls of blood vessels, which makes the latter more expanded compared to individuals of groups 2 and 3. Perhaps this phenomenon ensures the creation of the most optimal conditions for more intensive blood flow during active muscle work [4]. Most likely, this is a consequence of reduced sympathetic nervous influences that provide basal vascular tone [7, 12], and can also be explained by the systematic powerful release of vasodilator metabolites from the hypertrophied skeletal muscles of bodybuilders during regular strength training.

It is also worth noting that untrained young men are characterized by the highest values of all analyzed parameters (except MBV), which gives grounds for asserting that the tone of their blood vessels is formed due to stronger, compared to group 1, sympathetic influences [23]. In persons engaged in fitness, central hemodynamic indicators differ by intermediate values compared to representatives of groups 1 and 3, which may be a consequence of the balance between sympathetic influences and the action of biologically active substances-vasodilators, which are metabolites of skeletal muscles.

Immediately after a static load, a significant decrease in MBV is observed in individuals of groups 2 and 3, which can be explained by the effect of straining when performing a static effort, as well as by squeezing the walls of blood vessels with a simultaneous decrease in the venous return of blood to the heart. Accordingly, thanks to the myogenic and nervous mechanisms of heart regulation, cardiac output will be reduced, which leads to a decrease in MBV [2, 21]. In young bodybuilders, on the contrary, there is an increase in MBV even in the conditions of a powerful static effort, which was mainly provided by an increase in the force of contractions of the left ventricle and a corresponding increase in stroke volume [1, 16].

The growth of MBV in young bodybuilders is a physiologically appropriate reaction of the cardiovascular system to static physical exertion, this phenomenon is a manifestation of a high degree of functional reserves of the heart. These reserves are caused by an increase in the force of heart contractions (due to physiological hypertrophy of the myocardium of the left ventricle with a sufficient degree of capillarization) and physiological dilatation of the chambers of the heart, in particular, the left ventricle, which provides the necessary end-diastolic volume [13, 29].

Immediately after a static load, an increase in SPR and TPR parameters, as well as the tone of large-caliber arteries, was registered in all the examined persons. Thus, there is a narrowing of main large arteries, as well as pre- and post-capillary resistance vessels (mainly arterioles and venules), which is a consequence of the vasoconstrictor effect of hormones and mediators of the sympatho-adrenal system [3]. This is most significant in the fitness group and the least in bodybuilders, which is evidence that it is the young men who are engaged in bodybuilding who are the most adapted to static loads, in contrast to persons who are engaged in fitness and show the least degree of training of the circulatory system to physical exercises of a static nature.

It is worth noting that TPR reflects not only the state of the tone of the resistive vessels, but also the volume of blood entering them. If at the same time there is an increase in MBV against the background of a slight increase in mean dynamic pressure, as in the representatives of the group of bodybuilders, it can be assumed that the resistance of arterioles and venules is not high. However, this is not evidence of a change in the lumen of resistive vessels. Perhaps this is a consequence of the growth of the volumetric velocity of expulsion and the increase in the power of the left ventricle, which we observe in individuals of group 1. That is, it is a physiological mechanism of maintaining optimal conditions for the exchange of water and nutrients between blood plasma and tissue fluid.

Already 1 min after SL, all examined young men observed a decrease in the SPR, TPR, and tone of large-caliber arteries, which is evidence of the fact that the initial narrowing of the main arteries, arterioles, and venules is replaced by their significant expansion. This phenomenon can be explained by the leveling of the effect of catecholamines under the action of the powerful release of metabolites-vasodilators from skeletal muscles, a greater proportion of beta- than alpha-adrenoceptors in the cell membranes of myocytes of blood vessels of skeletal muscles and a local increase in temperature in actively working skeletal muscles [5, 9]. This is most pronounced in bodybuilders, who have the most developed and hypertrophied muscles, compared to untrained young men and those who engage in fitness.

DisIn and DiaIn parameters are characterized by quite interesting dynamics - in individuals of group 1, they decrease immediately after SL, in contrast to the values of similar parameters in individuals of groups 2 and 3, in which a rather significant increase was registered. The marked initial decrease in DisIn and DiaIn, which reflect the tone of arterioles and venous outflow, respectively, can be explained by the features of better adaptation of bodybuilders to SL, associated with the functioning of arterio-venous shunts in actively working skeletal muscles [14, 17]. The consequence of this will be a redistribution of the volume of circulating blood with an increase in the volume of blood in the collateral vessels, which will provide blood flow in the "bypass" of the compressed vessels.

In general, the most pronounced change in hemodynamic indicators in untrained individuals and young people engaged in fitness is a manifestation of the Lingard phenomenon and demonstrates a powerful postoperative increase in the functioning of the components of the circulatory system. It is due to the effect of straining during static effort, powerful squeezing of blood vessels and a decrease in the venous return of blood to the heart under the specified conditions. In contrast, body builders do not have a decrease in venous return due to a well-developed system of arterio-venular shunts. Against the background of the hypertrophied myocardium of the left ventricle and better adaptation to static efforts, this makes it possible for the circulatory system of bodybuilders not only not to decrease, but even to ensure the growth of such an integral parameter as minute blood volume. Thus, in young men who are engaged in bodybuilding, there is a decrease in the manifestation of the Lingard phenomenon.

Conclusions

1. In response to a static load, bodybuilding individuals experience an increase in minute blood volume and the most optimal physiological change in the hemodynamic parameters that provide it. In contrast to them, in young people engaged in fitness and in untrained individuals, the minute blood volume decreases and the conditions of central hemodynamics deteriorate immediately after exercise, which complicates the processes of rapid recovery after physical exercise in a static mode.

2. A decrease in vascular resistance to blood flow with a simultaneous increase in minute blood volume provides a better state of perfusion of the capillary bed of working skeletal muscles immediately after static exercise in young bodybuilders compared to young men engaged in fitness and untrained individuals.

3. The circulatory system of young bodybuilders is most optimally adapted to static loads compared to young men engaged in fitness and untrained individuals.

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ОСОБЛИВОСТІ ФУНКЦІОНАЛЬНИХ ЗМІН КРОВОНОСНИХ СУДИН В ПЕРІОД РАННЬОГО ВІДНОВЛЕННЯ ПІСЛЯ СТАТИЧНОГО ФІЗИЧНОГО НАВАНТАЖЕННЯ

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Серцево-судинна система є однією з провідних функціональних систем організму, які забезпечують та підтримують належний рівень фізичної працездатності організму при фізичних навантаженнях. Бодібілдинг є одним з напрямів спортивної діяльності, в якому урахування індивідуальних особливостей адаптації системи кровообігу до потужної м'язової роботи значної інтенсивності є визначальним для побудування оптимального тренувального режиму. Анатомо-фізіологічне ремоделювання серця внаслідок регулярних занять спортом призводить до змін насосної функції міокарда, а також показників центральної та периферичної гемодинаміки. Наразі існує проблематика недостатньої вивченості функціональних змін кровоносних судин у відповідь на статичний режим фізичного навантаження в ранньому післяробочому періоді. Мета дослідження - вивчення особливостей реакції кровоносних судин у період раннього відновлення після дозованих фізичних навантажень статичного характеру. Під час дослідження було обстежено 34 юнаків у наступних групах: 1 група - особи, які займаються бодібілдингом; 2 група - юнаки, які займаються фітнесом; 3 група - нетреновані особи. У всіх обстежених осіб за допомогою станового динамометра ДС-500 визначали максимальну довільну станову силу, статичне навантаження моделювали шляхом утримання на становому динамометрі протягом 30 секунд зусилля, яке відповідало 50 % від максимальної станової сили. Функціональні зміни кровоносних судин та центральної гемодинаміки реєстрували методом тетраполярної грудної імпедансної реоплетизмографії за допомогою комп'ютеризованого діагностичного комплексу "Кардіо+" (Україна). Статистичну обробку даних проведено за допомогою комп'ютерної програми IBM SPSS Statistics (версія 26), із використанням непараметричних методів оцінки отриманих результатів. Встановлено, що статичне навантаження у юнаків-бодібілдерів призводить до збільшення хвилинного об'єму крові за рахунок оптимальних фізіологічних змін параметрів центральної гемодинаміки. У осіб, які займаються фітнесом та у нетренованих юнаків, відбувається зменшення хвилинного об'єму крові та погіршення умов циркуляції одразу після навантаження, що ускладнює процеси швидкого відновлення після фізичного навантаження у статичному режимі. Виявлено зменшення опору судин току крові з одночасним зростанням хвилинного об'єму крові одразу після статичного навантаження у юнаків-бодібілдерів порівняно з особами, які займаються фітнесом та нетренованими особами. Встановлено, що система кровообігу юнаків-бодібілдерів найбільш оптимальним чином адаптована до статичних навантажень порівняно з особами, які займаються фітнесом та нетренованими юнаками.

Ключові слова: *кровоносні судини, центральна гемодинаміка, статичне навантаження.*