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Muscle and blood pressure quality features in strength athletes with arterial hypertension after aerobic exercise: a randomized controlled trial

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Objective
To assess the effect of intensified muscles oxidation on blood pressure (BP) in strength athletes with arterial hypertension.
Materials and methods. The study was performed at the Department of Sports Medicine of Russian State University of Physical Culture, Sport and Tourism and lasted for 180 days. The study included 65 power athletes from heavyweight categories with arterial hypertension. Athletes were randomized into three groups: HIIT (n=23), MICE (n=22) and RT (n=20). The following methods were used: blood pressure assessment, ergospirometry, measurement of the muscle tissue oxygenation, mathematical and statistical analysis. Athletes in the HIIT and MICE groups performed velergometry 3 times a week according to high intense interval and steady training protocols, while athletes from RT group had their regular power exercise training 3 times a week.
Results. Athletes who performed velergometry for 180 days showed the increase of oxygen consumption at the anaerobic burden, from the HIIT group — at 8,6 $ml \cdot kg^{-1} \cdot min^{-1}$, and from MICE group — at 7,7 $ml \cdot kg^{-1} \cdot min^{-1}$, and showed the decrease of oxygenation of the lateral head of the quadriceps femoris between the HIIT, MICE and control RT groups by 16.4 % and 11.4 %, respectively, which was accompanied by the decrease of systolic BP by 11.1 mm Hg and diastolic BP by 11.2 mm Hg on average.
Conclusion. The developed programs of aerobic exercise for strength athletes allows to safely and effectively influence the oxidative abilities of skeletal muscles and BP, however, athletes who followed HIIT protocol spent 38 % less time on non-specific training activities compared with MICE protocol that makes high intensity interval training the most effective and convenient method.

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According to the epidemiologic data, cardiovascular disease (CVD) is the leading cause of death and disability worldwide [1–3]. Muscle quality (MQ) is defined differently by clinicians and researchers. Geriatric medicine and gerontology describe the concept of MQ, comprised by glucose metabolism, oxidative damage, protein metabolism, intramuscular adipose tissue, capillary density, structural compound, contractility and fatigue [4]. Although there is no consensus on muscle quality, ambiguity of this term allowed to investigate several aspects of MQ in both older [5] and younger [6] individuals. Understanding of MQ phenotype characteristics is required to build physical rehabilitation systems that priorities functional improvement over muscle enlargement. It could be important in populations that are not limited by older people and include athletes and young active individuals who regularly perform difficult physical activities as parts of competitions or professional objectives. It is well known that physical exercise could help prevent and cure some chronic metabolic conditions. Therefore, a common concept of physical exercise being one of the medical treatments has developed. However, compared to the most medications, the mode of exercise necessary for better oxidative function and muscle metabolic health still remain controversial. It is well known that physical exercise with additional weights promote muscle strength and mass but at the same time are associated with reduction in mitochondrial volume in skeletal muscle (a phenomenon described as "mitochondrial volume dilution") [8]). It can also suppress mitochondrial growth in muscle fibers (MF) that grow during exercise with weights [9]. It is also well known that skeletal muscles demonstrate a significant heterogenicity not only in MF types but also in capillary distribution. Moreover, different exercise modalities have different effects on the growth and the number of capillaries in the working muscles [10]. For example, athletes who train to improve their endurance, are known for their well-developed capillaries compared with those who don't train enough or who do power sports. They a have high level of capillaries around the MF (~5–8), a high ratio of capillaries to MF (~2,5–3,0) and a high capillary density (~400–700 cap/mm^2). Untrained people have 3–4 capillaries around a MF compared with professional rally and track cyclists who have up to 9 capillaries around a MF [11].

CVD is a leading cause of morbidity and mortality all over the world, and the prevalence of CVD increases with age [12]. An increased blood pressure (BP) or a diagnosed arterial hypertension (AH) are widely recognized as the main CVD precursor. The risk of CVD is thought to be in a linear association with BP values. The identification of the main mechanisms of AH is crucial as for every 20 mmHg increase in BP doubles the risk of CVD. An association between the inflammation, reactive oxygen specials and vascular dysfunction is termed a "vascular health triad", which influences the BP regulation [13, 14]. Therefore, vascular health and the number of capillaries should be included in the concept of MQ.

AH is a common diagnosis in power athletes irrespectively of the kind of sport. At the same time, such athletes rarely use do cardiologic rehabilitation based on the aerobic exercise (Class 1A recommendations for patient with CVD that causes the reduction in CVD risk, repeated hospital admission, cardiovascular events and mortality [15]) Aerobic exercise increases maximal oxygen consumption (VO2 max) and the number of capillaries and mitochondria in CVD patients [16] leading to lower AH. Based on the analysis of this problem, research data and the request of sport physicians, trainers and power athletes we have formulated the aim of the study.

Aim — to evaluate the rise of the muscle oxidative capacity on blood pressure in power athletes with AH.

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Materials and methods

The study was carried out at the Department of Sport Medicine, Russian State University of Physical Education, Sports, Youth and Tourism and lasted for 180 days. The study included 65 power athletes with the mean weight of 105,9 ± 0,4 kg with AH. Informed consents were obtained from all the participants prior to enrollment according to Ethical Standards in Sport and Exercise Science Research, 2020 Update [17] (protocol № 5, Ethical Committee Meeting on 26.10.2017). Randomized controlled study was carried out according to the CONSORT study [18]. The athletes were randomized into the two groups (study group and control group) and using the random number tables: HIIT group (High Intensity Interval Training, n=23), группа MICE (Moderate Intensity Continuous Exercise, n=22) and control group RT (Resistance Training, n=20).

Inclusion criteria were: power athletes (men); heavy weight division (≥95 kg); aged 18–40 years; have sports category; have high blood pressure: SBP≥130 mmHg; DBP ≥85 mmHg; absence of any inflammatory of chronic diseases that could worsen by the time of examination; signed informed consent form according to Helsinki declaration.

Exclusion criteria were: age of power athletes of heavy weight division (≥95 kg) less than 18 and more than 40 years; power athletes of heavy weight division (≥95 kg) who has been training for less than 3 years; power athletes of heavy weight division (≥95 kg) who had SPB<130 mmHG, DBP<85 mmHg at the time of the study; power athletes of heavy weight division (≥95 kg) who had acute inflammatory or decompensated chronic conditions that could influence the results.

The athletes who weren't compliant with the study were also excluded.

The program, protocols and randomized clinical trial design were developed based on the modern concepts and rules of evidence-based medicine that were used according to the objective of the study.

Ergospirometry. Anaerobic threshold and VO2 max evaluation were performed using the tests with increasing cycle loading at the 75 revolutions per minute to maximum. The «MONARK 839 E» (Monark AB, Sweden) veloergometer was used. The loading was gradually increased from 20Wt by 20 Wt every 2 minutes. Gasometrical analysis was performed using the "CORTEX" (Meta Control 3000, Germany) analyzer that measures oxygen use and carbon dioxide excretion from inhaling to exhaling. Heart rate and the R-R intervals were assessed using the "POLAR RS800" (Finland) monitor. The test was stopped when >1.1 breathing coefficient was reached, the oxygen consumption graph reached plato for 30 seconds and if the patient was unable to continue pedaling at the given speed (increase or decrease for more than 10 RPM). Anaerobic threshold was evaluated according to the point of ventilatory equivalent for carbon dioxide (VE/VCO2) first increase with even larger increase in ventilatory equivalent for oxygen (VE/VO2) and the beginning of the partial pressure of end tidal CO2 (PetCO2). VO2 max was identified as the highest value of oxygen consumption of the two consecutive 15 second episodes at plato.

Change of the lateral head of the quadriceps femoris. The change of the lateral head of the quadriceps femoris oxygenation was evaluated using the "Moxy Monitor" (USA). Infrared sensor was placed on the lateral head of the right quadriceps femoris at the point of nerve entry. The mean skinfold thickness under the sensor (measured with Lange caliper, USA) in the main group athletes was 22 ± 2,2 mm and in the control group athletes was 23 ± 1,7 mm. The skinfold is formed of the two layers, therefore, the distance to the muscle is 10–12mm, which is relatively informative for this test (the depth of the scanning surface of the infrared "Moxy" sensor is up to 2.5 cm). The difference between the skinfold thickness between the two groups wasn't statistically significant. "Moxy" is a reliable instrument for muscle hemoglobin saturation during physical activity [19].

Blood pressure measurement. According to the clinical guidelines that were developed by the Russian Society of Arterial Hypertension and approved on November 28, 2013 at the plenum meeting and by the cardiology commission on November, 29, 2013, BP measurements were performed via self-measured blood pressure monitoring (SMBP). SMBP involved using traditional automated certified home tonometers. Three readings were taken in the left arm in succession, separated by at least 1 min in the morning (from 7:00 to 8:00). Mean values were recorded in the archive protocol.

Physical rehabilitation of hypertensive power athletes. Physical rehabilitation system consisted of the two methods (aerobic exercise combined with strength exercise) performed for the 6 months (72 sessions, 3 times per week). The system also included regular retests (at the end of each month) on the veloergometer in order to correct the exercise load in the aerobic physical rehabilitation protocol. The participants exercised according to the following protocols:

RT control group: weight training consisted of 5 exercises with weights of 70–90% of 1 repeated maximum (1RM), from 2 to 8 repetitions in 4 sets. One cycle of "set and rest" (until full recovery) was 5 minutes. The exercises were aimed at all the main muscle groups and included: barbell bench press, barbell squats, Romanian deadlift, biceps curls, triceps extension. The training session lasted for 100 minutes.

HIIT main group: weight training consisted of 5 exercises with weights of 70–90% of 1RM, from 2 to 8 repetitions in 3 sets. The method was identical to the control group. Aerobic exercise was added after the weight protocol. It consisted of 7 highly intensive intervals (cycle loading at the 100% of the maximal RPM) for 2 minutes and low intensive intervals with HR at 85% of anaerobic threshold according to the 2019 Sport Medicine College guidelines for people with AH. At the end of each month the athletes have undergone veloergometry testing according to the step protocol for load correction in the aerobic protocol of physical rehabilitation. The training session lasted for 100 minutes.

Statistical analysis

Statistical analysis was performed with Statistica 13.3 software. An assessment of the normality of data was performed with the Kolmogorov-Smirnov test. Multiple factor dispersion analysis with 3*2 repetitions for "regimen" (HIIT/MICE/RT) and "time" (before/after) was used to evaluate significant differences. First, the significant influence of the factors or their interaction were determined. Second, post hock test with Bonferroni correction was performed to evaluate pair-wise significant differences. Additionally, a paired t-test was performed to confirm intragroup changes in "time" before/after (0/60 60/120 120/180 and 0/120). P-values ≤0.05 and ≤0,01 were statistically significant. We present the results of posteriori tests in the description in the descending order of the contributing factor/interaction of factors.

Results and Discussion

Prior to the beginning of physical rehabilitation program,veloergometry with the gradually increased loading was performed in order to evaluate anaerobic threshold and VO2 max. Anaerobic threshold and VO2 max weren't statistically different in the athletes from the HIIT, MICE, and RT groups ($p<0,05$). After 180 days of physical rehabilitation anaerobic threshold and VO2 max increased in HIIT and MICE groups (Table 1). Anaerobic threshold increased in the HIIT and MICE by 8,6 ml·kg^{-1}·min^{-1} and 7,7 ml·kg^{-1}·min^{-1} respectively ($p<0,01$). Moreover, after 180 days of rehabilitation VO2 max increased by 9,2 ml·kg^{-1}·min^{-1} and 8,3 ml·kg^{-1}·min^{-1}, in the HIIT and MICE groups respectively ($p<0,01$).

In the control group RT oxygen consumption at anaerobic threshold increased by 0,2 ml·kg^{-1}·min^{-1} and VO2 max increased similarly by 0,2 ml·kg^{-1}·min^{-1}. These changes were not statistically significant. After 180 days of rehabilitation oxygen consumption at anaerobic threshold increased by 0,9 ml·kg^{-1}·min^{-1} in the HIIT group compared with MICE group ($p<0,01$). We have also identified statistically significant rise in the oxygen consumption at anaerobic threshold between the HIIT and RT groups (8,4 ml·kg^{-1}·min^{-1}) and between the MICE and RT groups (7,5 ml·kg^{-1}·min^{-1}) ($p<0,01$). After 180 days of rehabilitation, we have identified statistically significant rise in the VO2 max by 0,9 ml·kg^{-1}·min^{-1} in the HIIT group compared with MICE ($p<0,05$). There were also statistically significant differences in the VO2 max between the MICE and RT groups (9,0 ml·kg^{-1}·min^{-1}) and between the MICE and the RT groups (8,1 0,9 ml·kg^{-1}·min^{-1}) ($p<0,01$).

Near-infrared spectroscopy (NIRS) could be used for muscle mitochondrial capacity measurement as

Table 1. **Ergospirometry parameters in power athletes, (M±m)**

Group (N=65)	Anaerobic threshold (ml·kg^{-1}·min^{-1})			VO2 max (ml·kg^{-1}·min^{-1})		
	0 days	180 days	Δ	0 days	180 days	Δ
HIIT (n=23)	24,5±0,9	33,1±0,5	8,6*	31,7±1,2	40,9±0,6	9,2*
MICE (n=22)	24,2±0,8	31,9±0,4	7,7*	31,3±1,3	39,6±1,0	8,3*
RT (n=20)	24,1±0,8	24,3±0,7	0,2	31,5±1,4	31,7±1,3	0,2

Note. * — statistically significant differences in the parameters between the two groups before and after the rehabilitation. P<0,01.

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Table 2. **Lateral head of quadriceps femoris muscle oxygenation in power athletes, (M±m)**

Group (N=65)	Before the test			After the test		
	SmO2 (%) beginning	SmO2(%) end	Δ	SmO2(%) beginning	SmO2(%) end	Δ
HIIT (n=23)	59,0±6,6	38,9±6,4	20,1	59,1±6,7	22,3±6,7	36,8*
MICE (n=22)	58,5±7,1	39,7±8,1	18,8	59,0±6,9	28,5±6,9	30,5*
RT (n=20)	58,5±7,2	40,1±7,2	18,4	58,6±7,4	39,9±7,4	18,7

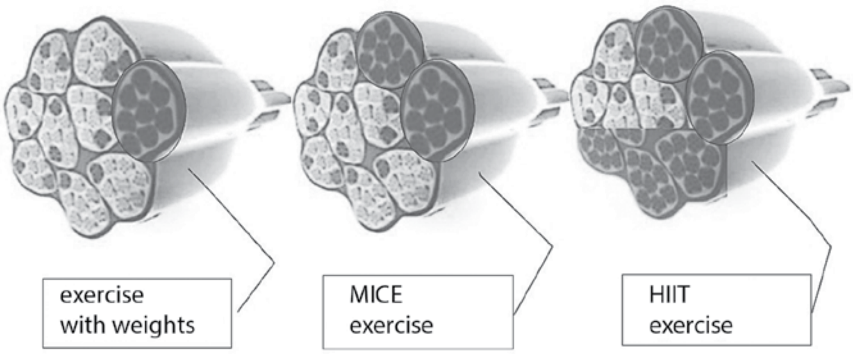
Note. * — statistically significant differences in the groups before and after the rehabilitation ($p<0,01$).

mitochondrial capacity correlates with aerobic training parameters [20]. Prior to physical rehabilitation all power athletes had to undergo veloergometry testing according to the step protocol. During that test lateral head of quadriceps femoris latent oxygenation was measured. The differences in the lateral head of quadriceps femoris muscle oxygenation in the athletes in the HIIT, MICE and RT groups after the first step test were not statistically significant ($p<0,05$). The difference between the oxygen consumption of the lateral head of quadriceps femoris muscle at rest and at the maximal activity (at the end of the step test) in the HIIT, MICE and RT groups were 20,1 %, 18,8 % and 18,4 %, respectively (Table 2).

After 180 days of rehabilitation lateral head of the quadriceps femoris muscle oxygenation decreased by 5,0 % in the HIIT group compared with the MICE group ($p<0,01$) at the end of the step veloergometry testing. Statistically significant differences in the quadriceps femoris muscle oxygenation between the HIIT, MICE and RT groups were 16,4 % and 11,4 % respectively ($p<0,01$).

It is well knowт that regular aerobic exercise increase VO2 max due to adaptation that increases oxygen transport, delivery and consumption. VO2 max in skeletal muscles rises due to mass and mitochondrial function increase during regular exercise. Mitochondrial capacity is tightly associated with VO2 max. It is a strong indicator of metabolic function and health [21]. In general, the MICE and HIIT protocols are associated with similar mitochondrial biogenesis signal protein reactions that are specific for MF type [22]. However, according to the 4 meta-analyses [23–26], HIIT had positive effects on oxygen consumption at lactate and ventilation thresholds. According to the studies that directly compared HIIT and MICE effects on VO2 max, there was also some positive effects on HIIT. Research showed that higher oxidative capacities of MF (capillarization and mitochondrial apparatus) were associated with lower total peripheral vascular resistance (one of the key factors that affect BP). Factors that are associated with low peripheral vascular resistance are poorly understood. However, it is well known that, compared with the type II MFs, the number of capillaries surrounding the type I MFs is higher and people with hypertension have lower capillary density that is associated with higher BP [27]. Power athletes have sufficient intensity and duration stimuli for MF hypertrophy; however, the duration of stimuli (time) is too short for the growth of capillaries and mitochondria. As such, we see this muscle quality in power athletes, in whom the number of muscles and strength potential are at the higher border and muscle biochemical profile is closer to glycolytic MFs. It is well known that longer aerobic exercise develops the mitochondrial apparatus [28] and working muscle capillarization better. At the same time, even aerobic exercise ("Gold standard" of physical rehabilitation in AH) creates sufficient stimulus for capillary and mitochondrial growth but only in the recruited MF (Picture 1). With this load (⩽anaerobic threshold) only low-threshold and intermediate MFs will have a sufficient stimulus for mitochondrial and capillary growth.

High-intensity interval training allows to recruit MFs over anaerobic threshold. If it is possible to hold the intensity for ⩾2 minutes, in the high-threshold MFs sufficient stimuli for mitochondrial and capillary growth will develop. During regular training below anaerobic threshold only low-threshold and intermediate MFs change the profile from glycolytic MFs to oxidative MFs. During high intensity interval training the number of mitochondria and capillaries increase in any type of MFs (low-threshold, intermediate and high-threshold) (Picture 1). It signifies that mitochondrial adaptation and capillary growth don't depend on the type of myosin MF but are based on the stimulus and this MF recruitment [29]. Eigendorf et al. [30] showed that high volume HIIT using the veloergometer leads to the shift of metabolic profile of high threshold MFs to type I phenotype (according to the



Picture 1. The effects of different training modalities on muscle oxidative properties.

glycolic → oxygative MFs). It increases the oxidative capacity and capillarization of high threshold MFs. Therefore, improvement of muscle quality (oxidative potential) has to improve BP in the study participants. After 180 days of rehabilitation in the HIIT and MICE groups BP decreased (Table 3).

According to the comparative study, after 180 days of training in the HIIT group there was a statistically insignificant reduction in SBP by 0,5 mmHg compared with the MICE group (p<0,05). Statistically significant differences in the SBP reduction between the RT and HIIT groups was 9,9 mmHg (p<0,01) and between the RT and MICE groups 7,8 mmHg (p<0,01). After 180 days of physical rehabilitation there was a statistically significant reduction in DBP by 0,8 mmHg in the HIIT group compared with MICE group (p<0,05). Statistically significant difference in the DBP reduction between the RT and HIIT groups was 10,3 mmHg (p<0,01) and between the RT and MICE group was 9,5 mmHg (p<0,01). Such a reduction in BP is a good prevention of CVD as it is well known that BP decrease by 7,5 mmHg and by 10 mmHg reduces the risk of stroke by 46& and 56%, risk of CAD by 29% and 37%. The reduction of SBP by 5 mmHg also decreased the risk of the main CV events by 10% independently of prior medical history of CVD [31]. Therefore, in the large randomized controlled study "Generation 100 study" that included 1567 patients, a trend towards the lower mortality from all causes after HIIT compared with cotrol and MICE was identified [32]. As per dynamics of BP (SBP and DBP) reduction, HIIT and MICE physical rehabilitation systems weren't significantly different. However, the time spent on HIIT rehabilitation was 38% lower.

Conclusion

The majority of muscle quality definitions don't take into consideration all the complex adaptations to their training stimuli and usually concentrate on two parameters (morphologic and neuromuscular). Such an approach could lead to wrong conclusions when evaluating the strength exercise. On the one hand, the muscle power and muscle diameter are significantly higher compared with the people with low level of physical activity, which should signify better health. On the other hand, low muscle oxidative capacity leads to higher BP and earlier mortality. At the end muscle quality should reflect functional summation of the complex physiological changes due to training adaptation. Therefore, a combination of power and aerobic exercise (HIIT or MICE) increases muscle quality and promote CV health in power athletes. Further randomized controlled trials are needed.

Conflict of interest: none declared.

Table 3. **BP changes in power athletes, (M±m)**

Group (N=65)	SBP (mmHg)			DBP (mmHg)		
	0 days	180 days	Δ	0 days	180 days	Δ
HIIT (n=23)	158,8±2,2	147,3±1,8	11,5*	101,3±3,3	89,7±2,7	11,6*
MICE (n=22)	159,2±2,5	148,2±1,9	11,0*	99,4±2,5	88,6±1,9	10,8*
RT (n=20)	157,9±2,3	156,3±2,8	1,6	98,5±2,3	97,2±2,1	1,3

Note. * — statistically significant differences in the groups before and after the rehabilitation (p<0,01).

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