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Original Article

D-ribose intake effectiveness for improving swimmer functionality

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Abstract
Athlete functioning in an elite division at the optimum level is not known to be effective without the application of dietary supplements. The aim of our study was to determine the exogenous ribose influence on the physiological and biochemical parameters of elite athletes, swimmers, in terms of physical fatigue. **Methods and Materials.** The study involved 83 male highly qualified swimmers. The athletes were divided into two groups: 1) athletes without complaints of fatigue and decreased workability (n=61) and 2) athletes with complaints (n=22). The swimmers in the 2[nd] group took ribose (manufactured in the USA) in a dose of 0.03 g/kg per single dose before and after every workout for a week. After completing the ribose intake regime, the athletes were retested. The results were processed using the statistical analysis package SPSS version 13.0. Under the normal distribution of variables, the obtained data were processed using the Student's criterion. In absence of a normal distribution, the Mann–Whitney U-test was used for statistical analysis. The differences between the average values were considered to be significant at $p<0.05$. **Results.** The decreasing physical workability and maximum oxygen consumption in the 2[nd] group of swimmers were 19.5% and 15.3%, respectively; the glutathione level decreased by 10.7% (P=0.01), the activity of glutathione peroxidase decreased by 16.3% (P=0.03), glutathione reductase decreased by 17.1% (P=0.02), and superoxide dismutase decreased by 16.5% (P=0.03). After a week of ribose intake, the workability of the swimmers was restored by 14.3%, and the maximum oxygen consumption increased by 9.7%; however, the index of stress decreased by 38.8% according to the heart rate variability data. The ribose intake increased the glutathione content in the erythrocytes by 10.5% ($P<0.05$), the glutathione peroxidase by 12.5% (P=0.04), and the glutathione reductase by 16.9% (P=0.04).
Conclusions. The results showed that exogenous ribose increased the functional state of swimmers and the antioxidant system capacity by replenishing the glutathione content and increasing the glutathione-dependent enzyme activity.
Keywords: fatigue, physical workability, athletes, antioxidant system

Introduction

The constantly increasing physical load intensity in professional sports is considered to be a necessary condition for achieving maximum results in competitions of various levels. This causes the emergence of a strain of the functional systems in athletes, followed by not only deteriorating the quality and effectiveness of professional activity, but also, in many cases, by the development of a number of pathological changes. An inopportune correction of physical loads in sports can result in fatigue or overtraining. In the latter case, the athlete has to be eliminated both from the training schedule and the competition calendar for several months (Badtieva et al., 2018; Decroix, Piacentini, Rietjens & Meeusen, 2016; Cardoos, 2015; Izzo, Rossini, Raiola, Cejudo Palomo & Hosseini Varde'i, 2020). For the medical and biological support of sports activities, it should include not only monitoring of trainees' functionality but also nutritional support to provide food and biologically active additives (BAA) to the daily meal plan (Zemtsova et al., 2020). The range of sports nutrition available today is quite extensive and includes various groups of additives: protein, carbohydrate, protein–carbohydrate supplements, vitamins, macro- and micro-elements, amino acids, and other components. According to foreign and domestic scientific data, many professional athletes (from 47 to 82.2%) have been using some type of sports supplements; moreover, in some countries, this figure can reach 100% (Jovanov et al., 2019; Nabuco et al., 2017).

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Ergogenic supplements are known to be especially popular among athletes because of their ability to increase physical endurance. For this purpose, using carbohydrate supplements has been important to sports medicine practice, and glucose and fructose-based supplements have become widespread. Numerous studies have confirmed the effectiveness of consumption of these carbohydrates by athletes to improve athletic results as well as the necessity of fractional supplemental intake during training (Froiland et al. 2004; Dmitriev & Gunina, 2018).

One promising means of improving physical workability is considered to be ribose monosaccharide, which is a structural component of ATP, ADP, FAD, NADP+, RNA, and other biologically important compounds. Under normal conditions, and more importantly, under hypoxic conditions, exogenous ribose contributes to replenishment of the required amount of ribose-5-phosphate to preserve the necessary level of pentose cycle function and to generate macroergic compounds. The role of ribose in mononucleotide biosynthesis has been shown because these processes are especially intensive under conditions of pathological alterations (Hellsten, Skadhauge & Bangsbo, 2004; Zolin & Konvay, 2018). Increasing the macroergic compound levels under the influence of ribose in cases of myocardial ischemia and heart failure has also been found (Shecterle & St.Cyr, 2014). Additionally, the beneficial effect of this monosaccharide has been noticed in a case of chronic fatigue syndrome (Teitelbaum, Johnson & St.Cyr, 2006).

However, studies concerning ribose effectiveness for maintaining the functional readiness of highly qualified athletes are insufficient. The data available in the scientific literature have not provided unambiguous scientifically substantiated conclusions regarding the possibility of ribose application under physical fatigue conditions to increase the efficiency of recovery processes in athletes. For example, in Kerksick et al. (2005), ribose intake of 3-g dose by cyclists was not found to show any statistically significant differences in glucose, lactate, or ammonia contents, or in fatigue onset for peak/average loads compared with a placebo group during anaerobic high-intensity cycling exercise (Kerksick et al. 2005). Additionally, Berardi et al. (2003) established a four-fold intake of eight grams of ribose under anaerobic cyclic loads for a 36-hour period to improve efficiency (Berardi & Ziegenfuss, 2003). In our published results, we have reported that it is necessary to maintain the function of the antioxidant defense system during intensive training to maintain physical workability (Kornyakova, Badtieva & Conway, 2020). Our publications showed the effectiveness of ribose to prevent catabolism of purine mononucleotides and reduce the intensity of lipid peroxidation in athletes who experienced fatigue (Kornyakova, Conway, Muratov & Fomina, 2015). The effect of ribose on antioxidant protection and the physical performance of swimmers have not been fully studied. The aim of our research has been to study the exogenous ribose influence on the physiological and biochemical parameters of functionality in swimmers under physical fatigue conditions.

Materials and methods

This study involved athletes, swimmers, of the first sport category, the categories of Candidate Master of Sport or Master of Sport. The athletes were examined during the preparatory period of trainings and characterized by intensified physical activity. The study involved 83 swimmers aged 19.5 ± 0.2 years and were divided into two groups according to anamnesis and questionnaires: the 1st group included those without any complaints of fatigue and decreased workability (n=61) and the 2nd group included those with complaints (n=22). To reduce fatigue and to improve recovery efficiency and physical workability, swimmers in the 2nd group were offered to take ribose monosaccharide (produced in the USA) at 0.03 g/kg per dose. The athletes took ribose before each workout and after completion of it for seven days. After the completion of the ribose intake course, the athletes were retested and made up the third group of subjects.

Anthropometric profile assessment, questionnaires, and physiological and biochemical parameters were used for the study. Heart rate (HR) and blood pressure (SBP and DBP) were measured at rest in the supine position. By performing the orthostatic test, the heart rate and blood pressure were measured again one minute after the athlete had taken a vertical position. The response of the autonomic nervous system was assessed using the scale offered by Makarova G. A. (Makarova, 2003). To estimate the heart rate variability (HRV) by RM. Baevsky, an electrocardiogram at rest in the supine position was recorded using the eight-channel computer electrocardiograph EK8K-01 "Poly-Spectrum-8 / EX" (produced by LLC "Neurosoft"). For the HRV data, the indicators of mode (Mo), mode amplitude (MoA), variation range (VRR), and Stress Index (SI) were analyzed.

To determine physical workability, the PWC_{170} ergo metric test was performed using the Seca Cardiotest 100 Bicycle Ergometer (UK). The duration of the first and second loading stages was 5 min with rest between loading stages lasting 3 min. At the 1st stage, the loading capacity depended on the athlete's weight, and at the 2nd stage, it depended on the heart rate (HR) recorded at the end of 1st stage loading. To determine the relative value of PWC170, the absolute value of the index was divided by the body mass index and was expressed as kgfm (kilogram-force-meter) / min / kg. To determine the index of maximum oxygen consumption (VO_2 max), this formula was used: VO_2 max =1,7 · PWC170 (kgfm /min)+1240. The relative value of VO_2 max was obtained by dividing the absolute value of this indicator by the body mass index and expressed in mL/ kgfm · min. The recovery period was estimated by the systolic and diastolic blood pressure (SBP and DBP) and HR within 10 min after the completion of the 2nd loading stage (Mikhajlov, 2005).

To perform the biochemical study, blood was taken from the ulnar vein immediately after morning training. To obtain the erythrocyte mass, the blood was centrifuged for 10 min at 3000 rpm. Then, the plasma was separated, and the erythrocytes were washed twice with 0.9% sodium chloride solution. Next, the erythrocyte mass was hemolized with distilled water (1:3). The antioxidant system component content in the erythrocytes was determined as follows: glutathione according to N. A. Kostromitikov et al. (Kostromitikov & Sumenkov, 2005), superoxide dismutase (SOD) according to T. V. Sirota (Sirota, 1999), glutathione reductase (GR) and glutathione peroxidase (GPO) according to S. N. Vlasova (Vlasova, Shabunina & Pereslegina, 1990).
All study participants were informed of the objectives and methods of the follow-up and signed a voluntary informed consent prior to participating. The follow-up was conducted in accordance with the requirements of the Helsinki Declaration. The study was approved by the Ethics Committee of Omsk State Medical University (Protocol No. 111 of 14.06.2019).

The results of the study were processed using the statistical analysis package SPSS version 13.0. Under the normal distribution of variables, the obtained data were processed using the Student's criterion. In absence of a normal distribution, the Mann–Whitney U-test was used for statistical analysis. The differences between the average values were considered to be significant at $p<0.05$.

Results

The anthropometric profile of the swimmers in both groups was appropriate for athletic model characteristics of this sports specialization; statistically significant differences in anthropometric parameters between the 1st and 2nd groups of athletes were not revealed. According to the study results, the second group of athletes complained of increased fatigue (77.3%), decreasing functional state (72.7%), and a reduced level of increase in sports results (54.5%). Some athletes in this group had complaints of irritability, an unstable state, flaccidity, disturbances in movement technique, anxiety, and other negative feelings. The investigation of HR and SBP at rest revealed increasing values of these parameters in the 2nd group of athletes. In subjects without any complaints of fatigue, the heart rate at rest was 63.7±1,1 beats / min, but it was higher than 9.4% (P=0.01) in the 2nd group of swimmers. The SBP value in the recumbent posture was 112±1 mm Hg for the 1st group of swimmers, and in the 2nd group swimmers, it was higher by 6.3% (P=0.03). According to the DBP indicator, no statistically significant differences were found between the first and second groups of swimmers in the recumbent posture.

When we analyzed the results of the orthostatic test, an increase in heart rate was noted in the 2nd group of swimmers. In athletes without fatigue, this indicator was 21,7±0,07, which was determined to be satisfactory. In the athletes in the fatigue group, this indicator was higher by 18% (P=0.004), and it was regarded as unsatisfactory.

In the group of swimmers with fatigue, MoA increased by 33.5% (P=0.008), and the SI increased by 137% (P<0.0001), whereas Mo and VRR decreased by 16.7% (P=0.003) and 45.8% (P<0.0001; Table 1), respectively. When assessing the overall physical efficiency and VO^2max for the 2nd group of swimmers, the decrease was determined to be by 19.5% (P<0.001) and 15.3% (P<0.01), respectively, compared with similar parameters in the 1st group of athletes. For the athletes in the second group, a delayed HR recovery was marked at the 10th minute in the recovery period after stress testing (this finding was 13.4% higher compared to the group of athletes without fatigue; P=0.001).

TABLE 1 **Indicators of heart rate variability in the swimmers**

Indicator / Athletes' group	Mo, sec.	MoA, %	VRR, sec.	SI, c.u.
Without fatigue (I), n=61	0.96±0.02	32.8±1.5	0.48±0.02	48.4±5.7
With fatigue (II), n=22	0.80±0.03*	43.8±1.8*	0.26±0.02*	115±14*
With fatigue+ribose (III), n=22	0.91±0,02^	34.4±1.7^	0.31±0.03^	70.4±4,5^

*Note: * - p<0.05 compared to the group of athletes without fatigue (I); ^ - compared to the group with fatigue (II).*

Glutathione content and GPO activity in the erythrocytes was lower in the second group of athletes by 10.7% (P=0.01) and 16.3% (P=0.03), respectively, than in swimmers in the first group. The activities of GR and SOD in the swimmers that complained of fatigue were reduced by 17.1% (P=0.02) and 16.5% (P=0.03), respectively, compared to swimmers in the first group, which was most likely due to the damaging effect of reactive oxygen species on these enzymes.

After the completion of the ribose intake, the number of athletes who were complaining of fatigue decreased by 45.5%, those who had a decreasing functional state decreased by 45.4%, and those who had a reduced growth of sports results decreased by 31.8%. There was a statistically insignificant decrease in HR, SBP, and DBP at rest under the influence of ribose. Inflow of this monosaccharide caused and increased the functional state of regulatory systems. The influence of ribose for HRV in the swimmers is shown in Table 1. In particular, we noticed an increase in Mo by 13.8% (P=0.04) and VRR by 19.2% (P=0.03) and a decrease in MoA by 21.5% (P=0.03) and SI by 38.8% (P=0.01), which indicated the restoration of vegetative balance in regulating heart function.

In athletes who those ribose, improving physical workability was found by the increase by 14.3% (P=0.01) of the PWC_{170}, and of the IPC index increase by 9.7% (P=0.03) compared with the same parameters measured before they took ribose. Under the influence of the monosaccharide, the recovery period efficiency after stress testing was increased at the 10^{th} minute of recovery; the heart rate particularly was 7.2% lower than in the second group of athletes (P=0.04). After ribose intake, the antioxidant enzyme activity increased: GPO by 12.5% (P=0.04), GR by 16.9% (P=0.04), and SOD by 11.5% (P>0.05). Restoration of activity of glutathione-dependent enzymes was likely achieved by the replacement of the glutathione content by 10.5% (P<0.05).

Discussion

During the preparatory work-out session that professional swimmers go through, their physical activity increases in intensity. However, when training under equal conditions, some athletes do not experience any excessive fatigue and have enough time to recover for the next training session; their physical workability is not reduced, whereas other swimmers are prone to becoming tired, which reduces their training activities' effectiveness. In connection with this, is very important to diagnose the fatigue state and to apply appropriate nutritional and metabolic support necessary for maintaining physical workability in a timely fashion. The attempt to correct physical fatigue by using exogenous ribose was examined in this study.

According to the performed questionnaire, applying this monosaccharide can be summarized as having positively influenced the subjective sensations of the swimmers in this study. There were also positive changes in the functional readiness of the athletes who took ribose. After ribose intake, enhanced physical workability was determined in patients who received ribose according to the tests of PWC_{170} and VO_2max indicator, which showed improvements in the functional state of athletes and increased aerobic capacity. According to orthostatic samples and heart rate variability estimates, a balance in the restoration of vegetative supplement regulation for the functionality of the athletes who took ribose was recorded. Orthostatic instability is known to be a limiting factor for physical efficiency. An excessive or insufficient vegetative response is evidence of decrease of some functional and reserve capabilities of an athlete's body (Shlyk, 2009). In addition, some studies have confirmed that the normal orthostatic vegetative stability in a training preparatory period has been found in only 50% of elite athletes. This is likely connected with more intensive physical loads at this stage of the training process (Iordanskaya F. A., Buchina E. V., Kochetkova N.I. & Nirka, 2017).

HRV indicators were found to be informative indicators of vegetative balance (Da Silva, De Oliveira & Silveira, 2015; Aubry et al. 2015). For example, in Le Meur Y. et al. (2013), parasympathetic influence predominance in the HRV parameters was found in triathletes with functional fatigue (Le Meur et al. 2013). Moreover, in athletes who constantly experience physical activity, HRV indicators are reliable prognostic criteria for sudden cardiac death. This is especially true for male athletes who have an increased sympathetic tone. The diagnostic value of the data obtained as a result of HRV examination of athletes has increased due to regular assessments of this indicator throughout the entire training year (Schäfer et al., 2015). According to studies by Vikulov A. D. et al. (2017), the current functional state of cyclical sports athletes (swimmers, skiers) may be assessed as appropriate if, according to HRV analysis, a moderate parasympathetic system predominance for managing heart rhythm is reported. Moderate bradycardia in swimmers and skiers is considered to be quite normal, when circulatory disorders do not develop and the contractile function of the heart is sufficient (Vikulov, Bocharov, Kaunina & Bojkov, 2017).

When examining the second group of athletes who felt fatigue, the predominance of the influence of the sympathetic nervous system on the heart rhythm and an elevation of the centralization degree of heart rate control was observed. The increase in the SI according to the HRV data indicated the tension of regulatory systems in the athletes in this group. The intake of ribose by athlete-swimmers contributed to the restoration of vegetative balance in heart functioning and to a decrease in SI.

Intensive physical activity is known to be followed by the occurrence of hypoxic shifts in the athlete body, which both disrupts normal progressing oxidative processes and contributes to oxidative stress development (Powers, Nelson & Hudson, 2011). Scientific studies have confirmed the increased generation of reactive oxygen species, which promotes the oxidation of glutathione, reduces the power of the antioxidant system, and results in fatigue occurs during intensive physical activity (Ferreira & Reid, 2008). When performing this research, some physical activities were likely followed by intensification of free radical oxidation processes in the swimmers in the second group, which reduced the functional activity of the antiperoxide protection system. The decreasing GR activity of swimmers who complain of fatigue is highly likely to be determined by the damaging effect of reactive oxygen species on this enzyme. GR inhibition indirectly inhibits glutathione disulfide reduction processes, which assists the decrease in glutathione production. The decreased content of this tripeptide in the 2^{nd} group of swimmers' erythrocytes followed a moderate inhibition of GPO activity. The active oxygen metabolites generated as a result of intensification of muscle activity have also produced an inhibitory effect on SOD activity in athletes with fatigue.

The glutathione-dependent enzyme activity and glutathione contents increased in the swimmers after they took ribose, which likely promoted more effective inactivation of peroxide compounds and stabilization of erythrocyte membranes. Increasing the antioxidant system power is one factor in restoring the athletes' functional state and improving aerobic capabilities during physical activity (Falone et al., 2009).

Conclusions

The results of this complex investigation of the functionality of highly qualified athletes (swimmers) confirmed the overload in the 2nd group followed by both adverse subjective sensations and by pronounced shifts in their physiological and biochemical parameters, which indicated decreased functional readiness. Highly sensitive prognostic markers of physical fatigue may include indicators of the antiperoxide protection system. Ribose contributed to improving the subjective status of the swimmers and their functional state, which may have been caused by the monosaccharide's ability to improve the reutilization of purine mononucleotides, thus preventing their involvement in catabolism reactions associated with increased active oxygen metabolite production (Zolin & Konvay, 2018). The exogenous ribose application provided increases in both physical workability (by 14.3%, P=0.01) and maximum oxygen consumption (by 9.7%, P=0.03) as well as the restoration of vegetative balance in heart rhythm regulation (SI decreased by 38.8%, P=0.01). Influence of this monosaccharide resulted in increasing the antioxidant system power: the activities of glutathione peroxidase (by 12.5%, P=0.04), glutathione reductase (by 16.9%, P=0.04), and glutathione (by 10.5%, $P<0.05$) in the red blood cells all increased. Ribose did not produce a statistically significant increase in superoxide dismutase activity. We can assume that the replenishment of glutathione and its metabolic enzymes, GPO and GR, is a necessary condition for improving the functional state of athletes and maintaining their physical workability during intense physical exertion. Moreover, we note that these ribose properties were shown with cyclic physical loadings that were of a high intensity and with a long course of taking this remedy for the athletes (during a week) who had complaints of fatigue. In addition to nutritional support in professional sports, it is necessary to take into account not only the specialty of training activities but also the metabolic characteristics of an athlete and the individual body reaction to the offered sports supplement (Klyuchnikov et al., 2018; Kerksick et al., 2017).

Conflicts of interest The authors declare no conflicts of interest.

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