STUDIES IN PHYSICAL CULTURE AND TOURISM
Vol. 13, No. 1, 2006

PIOTR BASTA [1], ANNA SKARPAŃSKA-STEJNBORN [2], ŁUCJA PILACZYŃSKA-SZCZEŚNIAK [3]
[1] Chair of Theory and Methodology of Physical Culture, Branch Faculty of Physical Culture in Gorzów Wlkp.
[2] Department of Hygiene, Branch Faculty of Physical Culture in Gorzów Wlkp.
[3] Department of Hygiene, University School of Physical Education, Poznań

# CREATINE SUPPLEMENTATION AND PARAMETERS OF EXERCISE-INDUCED OXIDATIVE STRESS AFTER A STANDARD ROWING TEST

**Key words:** creatine monohydrate, physical exercise, oxidative stress.

ABSTRACT

The aim of the study was to determine if, and to what extent, supplementation with creatine would induce changes in the oxidative stress parameters. The study was performed on twenty rowers in two groups. The test group was supplemented with creatine monohydrate for 35 days: initially 20g daily for five days, then 10g daily for the remaining 30 days. The control group received a glucose placebo. Prior to and after the 35$^{th}$ day of supplementation, the subjects performed an exercise on a rowing ergometer where the stress was graded from 50% of the maximal power up to a give-up point. The blood samples were tested for SOD, GPx and CK activity, TBARS concentrations, and LA. It was found out that supplementation with creatine did not induce any increase in the rowers' power, yet it led to the reinforcement of the antioxidative system in the rowers' blood, confirmed by a significantly lower concentration of lipid peroxidation products upon a 24-hour recovery period, and by a lower post-exercise activity of glutatione peroxidase.

## INTRODUCTION

Well-planned and organized physical training, biological predispositions and a regular diet do not always guarantee a sport success. Therefore, competitors search for nutrients and adjunctive preparations which would counteract and protect them against homeostasis disturbances evoked by excessive physical effort. Creatine monohydrate is a preparation that has been commonly used for this purpose since the 1990s.

Application of creatine monohydrate in sport exercise is justified by its physiological functions. It has been reported that creatine added to muscle fibers intensifies the synthesis of phosphocreatine [10]. *In vitro* creatine stimulates the synthesis of actin and heavy chains of meromyosin, and intensifies the rate of synthesis of contractile proteins by increasing the mRNA expression in differentiating as well as mature cells [1, 8, 15, 27]. The studies of Hultman and Sahlin [13] revealed that phosphocreatine had buffering properties and formed 30% of the buffer capacity of a muscle cell. This indicates that the ability to neutralize hydrogen protons dissociating from lactic acid leads to an increase in exercise capability, as the increase of the lactic acid concentration and the decrease of pH in muscles and blood are commonly regarded as factors limiting exercise capacity. Moreover, Saks [24] and Radd [21] suggested that the maximum oxygen

**Correspondence should be addressed to:** Piotr Basta, Branch Faculty of Physical Culture in Gorzów Wlkp., Estkowskiego 13, 66-400 Gorzów Wlkp., Poland, tel. 503147604, e-mail: maly197@interia.pl

absorption depended on the activity of creatine kinase, and that this activity was limited by the quantitative relations between creatine and phosphocreatine. According to Lawler [17], apart from the energetic function, creatine also functions as an antioxidant.

The aforementioned creatine properties, most of all its antioxidative properties, inspired us to put forward the following research questions: (1) Does supplementation of creatine modulate changes in parameters of oxidative stress induced by physical exercise of increasing intensity? (2) Does supplementation of creatine contribute to changes in athletes' threshold power?

## METHODS

The research was conducted on twenty elite rowers, members of the Senior Polish National Team. The tests were carried out in the Olympic Preparation Center in Wałcz, in May and June 2003, i.e., between the preparatory and the starting period of the annual training cycle. The competitors were randomly divided into two groups, the test and the control groups, composed of ten members each.

The subjects' basic anthropometric characteristics are presented in Table 1. The test group was supplemented with creatine monohydrate for 35 days. Initially, for 5 days, the subjects were given 20g of creatine monohydrate daily in four 5g doses dissolved in the Isostar carbohydrate nutrient (saturation dose). For the next 30 days they were receiving 10g of creatine monohydrate in two 5g doses (supporting dose). The competitors from the control group received a placebo in the form of glucose solution in the same doses and portions. In order to fully assess the results of supplementation, daily dietary intake of competitors was estimated (Table 2).

Before and after 35 days of supplementation, the subjects performed the ergometric exercise test, routinely applied in rowing, in order to estimate their physical capacity [25]. The exercise was performed on the Concept II rowing ergometer (USA). The competitors started with a load of 50% of the maximum power; then the load was increased every 3 minutes to 60, 70, 80 and 90% of the maximum power. The highest load was maintained until refusal. The maximum power was determined on the basis of a 2000 m control run. Individual 3-minute exercise sessions were separated with 30-second breaks.

**Table 1. Basic characteristic of the studied groups (mean ± standard deviation)**

| | Age (years) | Body mass (kg) | Body height (cm) | Years of training (years) |
|---|---|---|---|---|
| Supplemented group (n=10) | 21.6 ± 4.11 | 91.5 ± 7.65 | 193 ± 6.02 | 7.5 ± 4.16 |
| Control group (n=10) | 21.6 ± 1.64 | 85.8 ± 9.21 | 189 ± 5.69 | 7.6 ± 2.36 |

**Table 2. The daily energy and antioxidant vitamin intake in the supplemented and control groups (mean ± standard deviation)**

| | Supplemented group | Control group |
|---|---|---|
| Kcal | 4227.0 ± 442.7 | 4015.0 ± 769.4 |
| Proteins (g) | 189.0 ± 46.6 | 167.0 ± 25.2 |
| Fat (g) | 137.0 ± 29.2 | 127.0 ± 25.0 |
| Carbohydrates (g) | 560.0 ± 70.6 | 552.0 ± 25.0 |
| Vitamin A (IU) | 2241.0 ± 801.8 | 1949.0 ± 764.4 |
| Beta-carotene (IU) | 3233.0 ± 1465.6 | 2487.0 ± 1144.1 |
| Vitamin C (mg) | 118.0 ± 28.9 | 105.0 ± 32.5 |
| Vitamin E (mg) | 9.0 ± 1.7 | 10.0 ± 2.4 |

In the first and second periods of the study, before the test, one minute after its completion, and after 24 hours of recovery, venous blood was taken from the subjects' basilic vein (using polyethylene test-tubes with 1mg of $EDTAK_2$) and the capillary blood from the auricle. The blood was centrifuged (3000/min, for 10 minutes), the plasma and leukocytes were removed, and the red blood cells were rinsed three times with the physiological 0.9% NaCl solution at the temperature of 4ºC. In the haemolysate of red blood cells the following parameters were assessed: activity of superoxide dismutase (SOD) using the Randox diagnostic set (Randox-Ransel, Cat No. SD 125, UK); activity of glutathione peroxidase (GPx) using the Randox diagnostic set based on the method described by Paglia and Valentine [20] (Randox-Ransel, Cat No. RS 506, UK); concentration of thiobarbituric acid reactive substances (TBARS) with the spectrophotometric method by Buege and Aust [5]; and concentration of hemoglobin with Drabkin's method. In the blood plasma, the concentration of creatine and activity of creatine kinase (CK) were determined with an Emapol diagnostic set (Cat No. 12015, Poland). In the capillary blood the concentration of lactates was measured with the enzymatic method, using a Dr Lange set (Cat No. LKM 140, Germany).

The study was performed with the subjects' consent and was granted approval by the Local Committee for Scientific Research.

The results were statistically processed with STATISTICA 6.0 PL. The Mann-Whitney test was used for analysis of independent variables, and Wilcoxon's test for analysis of dependent variables. Correlations were assessed with Spearman's rank correlation coefficient.

## RESULTS

The results of the research are presented in Tables 1-5. Table 1 presents basic anthropometric characteristics and the rowers' sports experience. The rowers from the supplemented group were characterized by higher body mass (6 kg more on the average) and body height (4 cm taller on the average). Differences in the length of training period in years were statistically non-significant.

Table 2 contains values of the mean daily energetic intake and the amounts of main dietary components. No significant dietary differences were found between the groups under study, and the mean contents of respective components was in agreement with values recommended for men with a high level of physical activity [30].

The structure of training and the amount of work performed during 5 weeks before the first study period, and during 5 weeks between the first and the second study periods, are given in Table 3. The differences between the amounts of loads applied during individual training periods of rowers are due to the program principles of the annual training cycle. The specialist training on water consisted of about 80% of anaerobic loads that did not increase the lactate level above 2-3 mmol/l; 18% of loads exceeded the anaerobic threshold (the lactate level between 4 and 6 mmol/l). About 2% of the training time featured exercise with forced anaerobic metabolism (the lactate level above 8 mmol/l). Exercises on the rowing ergometer were aerobic – with the lactate level between 2 and 4mmol/l. During the endurance training the lactate level was 4-6mmol/l. The intensity of cross-country, swimming and systemic exercises did not raise the lactate level over 2mmol/l.

Table 4 contains a comparative analysis of the mean values of power and physiological parameters between the first and the second study periods for competitors from the supplemented and control groups. The power at which the subjects of the supplemented group achieved the anaerobic threshold (AT) in the second period decreased by 17 W, with a parallel decrease of the mean heart rate by 3 bpm (differences statistically non-significant). In the control group, no such changes were noticed. In the second study period, the standard ergometric rowing exercise in competitors from both groups led to an increase in the lactate concentration by 2 mmol/l, in comparison with the first period. Moreover, in the control group, the mean time of exercise performance was longer in the second term by about 14 s.

Table 5 shows a comparative analysis of the biochemical parameters before and after supplementation in the groups under study. In the supplemented group, a significantly lower activity of glutathione peroxidase was determined in the blood taken one minute after the exercise test in the second study period, in comparison to the first period ($p<0.005$). After 24 hours of recovery a significant decrease of TBARS concentration was also noted ($p<0.05$). No significant changes of the studied parameters were observed between both study periods in the control group. In both groups, concentrations of creatine kinase were significantly higher in the second period, either at rest after the exercise test or after the 24-hour recovery period.

**Table 3. Training structure and the work performed in hours**

| Type of training | I term [h] | II term [h] |
|---|---|---|
| Specialist training on water | 25.5 | 45.5 |
| Endurance | 16.5 | 9 |
| Cross-country and stadium run | 8 | 3 |
| Exercises on the rowing ergometer | 12 | 4 |
| Exercises at the gym and the swimming pool | 2.5 | 1.5 |
| **Together** | **64.5** | **63** |

**Table 4. Comparative analysis of mean values of power and physiological parameters between I and II terms of the study in the supplemented and control groups**

| Parameter | Supplemented group | | | Control group | | |
|---|---|---|---|---|---|---|
| | I term x ± SD | II term x ± SD | Wilcoxon's test | I term x ± SD | II term x ± SD | Wilcoxon's test |
| Power AT (W) | 338 ± 33.06 | 321.3 ± 44.23 | n.s. | 320.6 ± 30.38 | 321.9 ± 28.51 | n.s. |
| Heart rate AT (bpm) | 174.3 ± 8.38 | 171.0 ± 8.35 | n.s. | 173.0 ± 5.56 | 173.3 ± 8.47 | n.s. |
| Heart rate max (bpm) | 192.6 ± 8.79 | 194.4 ± 8.02 | n.s. | 193.1 ± 4.93 | 193.8 ± 8.56 | n.s. |
| Exercise time (s) | 996.5 ± 50.44 | 999 ± 66.41 | n.s. | 978 ± 76.24 | 992 ± 106.54 | n.s. |
| LA max (mmol/l) | 11.7 ± 3.34 | 14.2 ± 2.51 | n.s. | 12.9 ± 3.54 | 14.6 ± 3.34 | n.s. |

n.s. – statistically non-significant; AT – anaerobic threshold (lactic acid, LA = 4 mmol)

**Table 5. Balance between oxidants and antioxidants before and after supplementation. Comparisons within the supplemented or the control groups (mean ± standard deviation)**

| | Supplemented group | | | Control group | | |
|---|---|---|---|---|---|---|
| | Before supplementation x ± SD | After supplementation x ± SD | Wilcoxon's test | Before supplementation x ± SD | After supplementation x ± SD | Wilcoxon's test |
| **TBARS** (μmol/gHb) | | | | | | |
| at rest | 1.4 ± 2.24 | 1.5 ± 0.63 | n.s. | 1.3 ± 1.24 | 1.3 ± 0.26 | n.s. |
| after ET | 1.7 ± 0.45 | 1.6 ± 0.36 | n.s. | 1.8 ± 1.68 | 1.9 ± 0.35 | n.s. |
| 24 h after ET | 2.3 ± 0.75 | 1.6 ± 0.38 | * | 2.2 ± 0.57 | 2.4 ± 0.71 | n.s. |
| **SOD** (U/gHb) | | | | | | |
| at rest | 1105.4 ± 83.27 | 1196.6 ± 91.68 | n.s. | 1127.2 ± 69.79 | 1142.9 ± 83.01 | n.s. |
| after ET | 1190.1 ± 81.66 | 1227 ± 106.19 | n.s. | 1217.5 ± 109.74 | 1272.8 ± 89.17 | n.s. |
| 24 h after ET | 1411.5 ± 98.24 | 1346.3 ± 102.6 | n.s. | 1391 ± 97.23 | 1403.3 ± 131.61 | n.s. |
| **CK** (U/l) | | | | | | |
| at rest | 36.8 ± 18.38 | 81.6 ± 32.40 | * | 35.2 ± 11.99 | 71.9 ± 35.69 | * |
| after ET | 42.9 ± 13.97 | 99.5 ± 32.55 | * | 39.2 ± 13.06 | 83.1 ± 27.19 | * |
| 24 h after ET | 41.2 ± 11.84 | 91.3 ± 33.66 | * | 33.1 ± 10.90 | 78.5 ± 32.62 | * |
| **GPx** (U/gHb) | | | | | | |
| at rest | 38.9 ± 9.71 | 39.9 ± 7.15 | n.s. | 42.4 ± 9.87 | 40.4 ± 10.81 | n.s. |
| after ET | 67.9 ± 10.86 | 43.5 ± 11.47 | * | 68.9 ± 12.12 | 62.1 ± 9.3 | n.s. |
| 24 h after ET | 47.0 ± 12.15 | 49.1 ± 9.41 | n.s. | 42.3 ± 9.91 | 45.3 ± 9.69 | n.s. |

The samples for analysis were collected at rest, 1 min after an incremental rowing exercise test (after ET), and after a 24-h recovery period (24 h after ET).

n.s. – statistically non-significant difference; * – difference significant at $P \leq 0.05$; TBARS, thiobarbituric acid reactive substances; SOD, superoxide dismutase; CK, creatine kinase; GPx, glutathione peroxidase

## DISCUSSION

Positive influence of supplementation with creatine monohydrate on the course of a rowing race has been confirmed in several studies. Rossiter et al. [23] indicated a significant improvement of the time in a control 1000m run in British rowers supplemented with creatine, while Lawrence et al. [16] reported similar effects on a 2500-m distance.

In our study no positive effects of 35-days supplementation with creatine monohydrate have been found with respect to the parameters of rowers' physical capacity. The results were not confirmed with respect to the AT power, AT heart rate, time of the exercise test or lactate concentration (Table 4).

The power at which the competitors achieved the anaerobic threshold in the supplemented group was even slightly decreased (by about 17 W) in comparison with results obtained before supplementation. In the control group the mean power remained at the same level. The anaerobic threshold at the level of 4 mmol/l is acknowledged as an indicator of physical capacity [4, 6]. Wolf and Roth [26] confirmed the diagnostic usefulness of this parameter in their assessment of rowers' starting disposition. It is apparent from the results from Table 4 that creatine supplementation did not improve the oxidative power. In the supplemented group, the exercise time did not change in the second study period, while it was longer by 14 s in the control group. The rowers' starting period was chosen for the purpose of the study as during this time the rowers participate in numerous competitions and, moreover, they should have the highest predispositions to perform physical exercise.

The results obtained in this study confirmed beyond doubt that physical exercise on the ergometer with the intensity increasing from 50% of the maximal power until refusal, causes metabolic acidosis. The post-exercise increase of the lactate concentration in the second study period might be a result of the increased tolerance to acidosis – evoked by the training cycle during the conditioning camp, and on the other hand, of the higher contribution of an anaerobic component in covering the energetic costs of the exercise.

The exercise test used in this study contributed also to disturbances in the prooxidative-antioxidative balance towards the prooxidative processes. The presented results showed that despite regular intake of antioxidative vitamins, as recommended for men with a high level of physical activity [30], the antioxidant defense system in the competitors from the control group appeared to be less efficient than in the competitors from the group supplemented with creatine (Table 5). It was indicated by higher concentrations of lipid peroxidation products (TBARS) in the control group and lower post-exercise activity of gluthathione peroxidase (GPx) in the supplemented group in the second study period.

Lower concentrations of TBARS after the 24-hour recovery in the supplemented group in the second study period indicate a lower level of the oxidative stress in comparison with the control subjects. Such changes should be attributed to the antioxidative properties of creatine. Lawler et al. [17] determined *in vitro* that creatine had an ability to remove the superoxide anion radical, $ABTS^{+}$ cation, and peroxynitrite radical ($ONOO^{-}$); however, the ability to remove free radicals is lower for creatine than for glutathione, and plays rather a supporting than major role in antioxidant defense. Antioxidative properties of creatine may be linked to the presence of arginine in its molecule. Arginine is a substrate for calcium and calmodulin – dependent nitric oxide synthases [2]. Thus, the creatine intake may increase the production of nitric oxide in endothelial cells causing relaxation and decrease of blood pressure [22]. Other amino-acids, such as cysteine or methionine, contained in the creatine molecule are highly susceptible to free radical oxidation due to the presence of sulphydryl groups [9]. Different studies confirm that creatine evokes indirect antioxidative effects. This was proposed by Vergnani et al. [28], who revealed the protective function of arginine, the precursor of creatine, in the oxidative modifications of the LDL-cholesterol in endothelial cells and aortal rings. On the other hand, Matthews et al. [18] suggested that creatine might suppress the increased hypoxanthine efflux from the muscle during intensive exercise and generation of the superoxide anion radical by xanthine oxidase during the concurrent increased ATP catabolism [11]. Since creatine is soluble in the sarcoplasm and accessible for oxygen reactive forms generated during physical exercise, it may be regarded as a factor supporting antioxidant defense. This fact could play a significant role in reducing fatigue. The oxidative stress caused by excessive production of prooxidants and/or insufficient antioxidative ability increases degradation of myofibril proteins, which in turn leads to the fatigue of a contractile unit [3]. It is likely that the increased intracellular concentration of creatine needs lower amounts of arginine for energetic metabolism, so the latter becomes more accessible for nitric oxide products [17].

Yatin et al. [29] reported that the reactive form of oxygen inhibited creatine kinase (CK). In our study, the physical exercise of increasing intensity in both groups caused a significant rise in the activity of this intracellular enzyme in the blood plasma. In the supplemented group, the CK activity in the second study period was higher by more than 10 U/L in comparison with the control group. On the one hand, this higher CK activity may be an indicator of miofibrillar lesions; on the other hand, it could be an effect of higher saturation of muscle fibers with creatine, present in 60-70% in the form of phosphocreatine (PCr). Creatine kinase is an enzyme contributing to the synthesis of PCr by catalyzing reversible phosphate residues between PCr and ADP [12]. Although the hypothesis explaining the increase of CK activity in the supplemented group in the second study period by higher creatine and phosphocreatine concentrations in muscle fibers seems reasonable, the explanation of the double increase of the CK activity in the second study period in the control group remains a difficult one.

The activity of superoxide dismutase (SOD) determined in this study showed no significant differences between the groups under study, but the increase of the SOD activity was observed in both groups between both study periods, after the exercise test and after 24-hours of recovery. SOD is the enzyme defending a cell from cytotoxic effects of superoxide radicals and from their formation. Its activity increases in parallel to the increased physical activity. Products of dismutation are substrates for antioxidative enzymes, catalyse and GPx, which remove the hydrogen peroxide [19]. These enzymes are activated for reduction of reactive forms of oxygen (ROS) during the oxidative stress evoked by the muscular work, but often their activity is insufficient to build up effective defence against ROS, which leads to intensified peroxidation [14]. One should stress, however, that the rowers under study were elite competitors from the Polish National Team, with an average 8-year period of training. The years of endurance training could evoke adaptive changes of enzymatic antioxidative systems [7]. It is apparent that creatine supplementation decreased the post-exercise activity of GPx, the enzyme responsible for metabolism of hydrogen peroxide. This way a cell could be defended from excessive lipid peroxidation, which was indicated by lower levels of TBARS after the 24-hour recovery period, and which was not observed in the control group. In the latter the increased activity of antioxidative enzymes accompanied the considerable increase of lipid peroxidation products (Table 5).

In conclusion, the supplementation with creatine monohydrate did not influence the parameters of physical capacity; however, it contributed to the reinforcement of the antioxidant defense system in competitors' blood, which was proved by significantly lower levels of lipid peroxidation products after the 24-hour recovery period, a higher resting level of creatine as well as a lower post-exercise activity of glutathione peroxidase in the supplemented group. These observations suggest more conscious use of creatine as an additional protection from overproduction of reactive forms of oxygen.

## REFERENCES


[1] Balsom P.D., Harridge S.D., Soderlund K., Sjodin B., Ekblom B., Creatine supplementation per se does not enhance endurance exercise performance, *Acta Physiologica Scandinavica*, 1993, 149: 521-523.

[2] Bartosz G., Druga twarz tlenu (Another face of oxygen), PWN, Warszawa 1995.

[3] Benzi G., Is there a rationale for the use of creatine either as nutritional supplementation or drug administration in humans participating in sport, *Pharmacology Research*, 2000, 41: 255-264.

[4] Beneke R., Anaerobic threshold, individual anaerobic threshold, and maximal lactate steady in rowing, *Medical Science of Sports Exercise*, 1995, 27: 863-867.

[5] Buege J., Aust S.D., The tiobarbituric acid assay, (in:) C.A. Evans, A.T. Diplock., M.C.R. Symones, eds., Techniques in Free Radical Research, Elservier Amsterdam, London, New York, Tokyo, 1991, pp. 147-148.

[6] Chwalbińska-Moneta J., Koncepcja progu anaerobowego. Podstawy fizjologiczne i biochemiczne (The concept of an anaerobic threshold. Physiological and biochemical framework), Polskie Towarzystwo Medycyny Sportowej, Warszawa 1995.

[7] Evelo C.T., Palmen N.G., Artur Y., Janssen G.M., Changes in blood glutathione concentrations and erythrocyte glutathione reductase and glutathione S-transferase activity after running training and after participation in contest, *European Journal of Applied Physiology*, 1992, 64: 354-358.

[8] Greenhaff P.L., Bodin K., Soderlund K., Hultman E., Effect of oral creatine supplementation on skeletal muscle phosphocreatine resynthesis, *American Journal of Physiology*, 1994, 266: 725-730.

[9] Grune T., Reinheckel T., Davies K.J.A., Degradation of oxidized proteins in mammalian cells,

*Federation of American Societies for Experimental (FASEB)*, 1997, 11, pp. 26-534.

[10] Harris R.C., Soderlund K., Hultman E., Elevation of creatine in resting and exercise muscle of normal subjects by creatine supplementation, *Clinical Science (London)*, 1992, 83: 367-374.

[11] Hellsten Y., Frandsen U., Orthenblad N., Sjodin B., Richter E.A., Xanthine oxidase in human skeletal muscle following eccentric exercise: A role in inflammation, *American Journal of Physiology*, 1997, 498: 239-248.

[12] Hollmann W., Hettinger T., Sportmedizine arbeits und trainings grundlage (Nutrition and vitamins. Facts on Fil), Holmes A.M. Inc., Stuttgart, New York 1980.

[13] Hultman E., Sahlin K., Acid-base balance during exercise, *Exercise Sports Science Review*, 1980, 8: 41-128.

[14] Inal M., Akyuz F., Targut A., Getsfrid W.M., Effect of aerobic and anaerobic metabolism on free radical generation swimmers, *Medical Science Sports Exercise*, 2001, 33: 546-567.

[15] Kreider R.B., Ferriera M., Wilson M., Grindstaff P., Plisk S., Reinardy J., Cantler E., Effects of creatine supplementation on body composition, strength, and sprint performance, *Medical. Science Sports Exercise*, 1998, 30(1): 73-82.

[16] Lawrence S.R., Preen D., Dawson B., Beilby J., Goodman C., The effect of oral creatine supplementation on maximal exercise performance in competitive rowers, *Sport Medical Training and Rehabilitation*, 1997, 7: 243-253.

[17] Lawler J.M., Barnes W.S., Wu G., Song W., Demaree S., Direct antioxidant properties of creatine, Elservier Science, 2002.

[18] Matthews R.T., Yang L., Jenkins B.G., Ferrante R.J., Rosen B.R., Kaddurah-Dauok R., et al., Neuroprotective effects of creatinine and cyclocreatinine in animal models of Huntington' disease, *The Journal of Neuroscience*, 1998, 18: 156-183.

[19] Ohno H., Sato Y., Yamashita K., The effect of brief physical exercise on free radical scavenging enzyme system in human red blood cells, *Canadian Journal of Physiology & Pharmacology*, 1986, 46: 1263-1265.

[20] Paglia D.E., Valentine W.N., Studies on quantitative and qualitative characterization of erythrocyte gluthatione peroxidase, *Journal of Laboratory and Clinical Medicine*, 1967, 70: 158-169.

[21] Radd G.K., Control of energy during muscle metabolism, *Diabetes*, 1996, 45: 88-92.

[22] Reid M.B., Redox modulation of skeletal muscle contraction: What we know we don't, *Journal of Applied Physiology*, 2001, 94: 2468-2474.

[23] Rossiter H.B., Cannell E.R., Jakeman P.M., The effect of oral creatine supplementation on the 1000-m performance of competitive rowers, *Journal Sports Sciences*, 1996, 14: 175-179.

[24] Saks V.A., Cardiac energetics: Compartmentation of creatine kinase and regulation of oxidative phosphorylation. Creatine and creatine phosphate, (in:) Scientific and clinical perspectives, San Diego Academic Press. 1996, pp. 65-76.

[25] Steinacker J.M., Lormes W., Stauch M., Sport Specific Testing in Rowing, Advances in Ergometry, Springer, Berlin-New York 1991, pp. 443-454.

[26] Wolf W.V., Roth W., Validiitat spiroergometrischer Parameter fur die Wettkampfleistung im Rudern, *Medizin und Sport*, 1987, 27: 162-166.

[27] Volek J.S., Duncan N.D., Mazzetti S.A., Staron R.S., Putukian M., Gomez A.L., Pearson D.R., Fink W.J. Performance and muscle fiber adaptation to creatine supplementation and heavy resistance training, *Medical Science Sports Exercise*, 1999, 31(80): 1147-1156.

[28] Vergnani L., Hatrick S., Ricci F., Passaro A., Manzoli N., Zuliani G., Brokovych V., Effect of native and oxidized low-density lipoprotein on endothelial nitric oxide and superoxide production: key role of L-arginine availability, *Circulation*, 2000, 101: 1261-1266.

[29] Yatin S.M., Aksenow M., Butterfield D.A., The antioxidant vitamin E modulates amyloid beta-peptide-induced creatine kinase activity inhibition and increased protein oxidation: Implications for the free radical hypothesis of Alzheimers disease, *Neurochemical Research*, 1999, 24: 427-435.

[30] Ziemlański Ś., Normy żywienia człowieka (Human dietary standards), PZWL, Warszawa 2001.