Journal of Applied Biomedicine 15 (2017) 133–138

Contents lists available at ScienceDirect

Journal of Applied Biomedicine

journal homepage: www.elsevier.com/locate/jab

Original research article

# The effect of different doses of zinc supplementation on serum element and lactate levels in elite volleyball athletes

Gunay Eskici[a,*], Mehmet Gunay[b], Abdulkerim Kasim Baltaci[c], Rasim Mogulkoc[c]

[a] *Erzincan University, High School of Health, Department of Nutrition and Dietetics, Erzincan, Turkey*
[b] *Gazi University, High School of Physical Fitness and Sport, Ankara, Turkey*
[c] *Selcuk University, Medical School, Department of Physiology, Konya, Turkey*

ARTICLE INFO

*Article history:*
Received 31 May 2016
Accepted 3 November 2016
Available online 5 November 2016

*Keywords:*
Athlete
Fatigue
Element
Zinc
Lactate

ABSTRACT

The present study aims to examine the effect of different doses of zinc administration on serum element metabolism and fatigue. The study registered 20 female elite athletes. The subjects were divided into two groups in equal numbers. Group supplemented with 220 mg/day zinc sulfate. Group supplemented with 440 mg/day zinc sulfate. Athletes who were already engaged in their daily training routines were put to a 20-m shuttle run test to create fatigue before and after supplementation. Blood samples were collected from the subjects for a total of 7 times, before and after zinc supplementation and during rest and after exercise within one-week intervals over the course of the 4-week supplementation. The blood samples collected as such were analyzed to determine serum magnesium, phosphorus and calcium, zinc, iron, copper, and selenium, and plasma lactate. Both exercise and zinc supplementations significantly elevated magnesium, calcium, and iron levels for 4 weeks. Pre-supplementation exercise elevated plasma lactate levels, while zinc supplementation led to a fall in plasma lactate. The results of the present study indicate that zinc-supplementation for 4 weeks may have a positive impact on athletic performance by delaying fatigue.



## Introduction

Involved in the structure of more than 300 enzymes in the living organism and essential for a variety of metabolic reactions, zinc is an important trace element (Vallee and Falchuk, 1993). As a number of immune and endocrine functions depend on zinc, its deficiency is associated with problems in some physiological activities including cell proliferation, wound recovery, bone metabolism, growth and development, brain functions, regulation of nutrition, etc. (Baltaci et al., 2004; Prasad, 2009a, 2009b, 2013). Zinc, which is essential for carbohydrate, protein, and fat metabolisms, is integrally related to exercise (Bicer et al., 2012; Vallee and Falchuk, 1993). Its effects on tissue repair and protein synthesis, in particular, indicates the importance of zinc in post-exercise recuperation (Kilic, 2007; Prasad, 1985). In addition to the effects of zinc on exercise and performance, exercise has critical effects on zinc metabolism. Previous studies showed that not only low-intensity exercise produced short-term effects on zinc metabolism, but also high-intensity exercise performed for a prolonged period could do so (Cordova and Alvarez-Mon, 1995). These studies demonstrated a decrease in zinc levels after exercise (Couzy et al., 1990; Haralambie, 1981; Khaled et al., 1999). Low zinc levels may lead to a fall in muscle zinc concentrations. As zinc is required for the activity of a number of enzymes in the energy metabolism, reduced muscle zinc levels may bring about a decrease in endurance capacity (Cordova and Alvarez-Mon, 1995). It may be that the zinc deficiency observed in athletes performing endurance training is a factor triggering various functional changes in different systems and tissues that may be associated with the pathogenesis of fatigue (Cordova and Navas, 1998).

McDonald and Keen (1988) have reported that it is important known of relationship between interaction diet zinc and other elements for sportsperson health and performance. It has been postulated that zinc has significant effects on element distrubution in body (Eskici et al., 2016); especially has on positive affects on calcium-phosphor metabolism özellikle kalsiyum-fosfor metabolizması (Baltaci et al., 2014) and zinc supplementation has

* Corresponding author.
*E-mail addresses:* g.eskici@yahoo.com (G. Eskici), mgunay@gazi.edu.tr (M. Gunay), baltaci61@yahoo.com (A.K. Baltaci), mogulkoc@selcuk.edu.tr (R. Mogulkoc).

http://dx.doi.org/10.1016/j.jab.2016.11.001

regulatory effects on magnesium, phosphor, calcium, iron, cupper and selenium levels (Sivrikaya et al., 2012). All of them mentioned references show posisble affects of zinc elements metabolism in sportsperson. The objective of the present study is to examine the effect of different doses of zinc supplementation on serum element metabolism and fatigue.

## Materials and methods

### *Participants*

The research included 20 female athletes who were on the volleyball team of Gazi University Sports Club and whose mean age, weight, and height were 15.1 ± 1.07 years (14–17), 59.9 ± 6.4 kg (50.4–72.2), and 175.3 ± 6.5 cm, respectively. The subjects (and/or their parents) who were verbally informed also signed copies of the Helsinki Declaration explaining who is conducting the study and why. The study protocol was approved by the Ethics Committee of Selcuk University School of Physical Education and Sports.

We have conducted the present research, each group of athletes's in resting and exhausting period lactate and serum element levels were determined; thereafter we postulated pre-measured periods as control levels. We have not used different control group.

The athletes in the study were divided into two groups:

Group 1 was supplemented with 220 mg/day zinc sulfate (Each 220 mg zinc sulphate has included 50 mg elemental zinc) and Group 2 was supplemented with 440 mg/day zinc sulfate (Each 440 mg zinc sulphate has included 100 mg elemental zinc). (Zinc sulfate capsules were supplied by Berko Drug and Chemicals Industry Inc. in the form of capsules each containing 220 mg zinc sulfate.) Mentioned doses were used previous search (Duchateau et al., 1981).

### *Procedures*

The athletes who continued their routine daily training (6 days a week) were put to a 20m shuttle run test before and after supplementation to induce fatigue (Gunay et al., 2006). 20 m shuttle run test, one of the aerobic power field test was performed in order to create just fatigue. Blood samples were collected from the subjects for 7 times before and after zinc supplementation and during rest and after exercise in one-week intervals over the course of 4 weeks. Blood samples (10 ml) were taken by specialist medical staff (nurse) from the forearm vein. Since the athletes were all females, the analyses were interrupted in the week they had their menstruation. The samples were stored at −80 °C until the time of analysis. The study was conducted during the 8- to 10-week general preparation period (consisting of 70–80% strength and 20–30% technical/tactical training) of the athlete group.

### *Serum zinc, magnesium, phosphorus, calcium, iron, copper, and selenium analyses*

Blood samples put into Eppendorf tubes were centrifuged at 3000 rpm for 10 min to separate serum. Serum samples obtained as such were analyzed for magnesium, phosphorus, calcium (mg/dl), zinc, iron, copper, and selenium (μg/dl) levels in an atomic emission device (ICP-MS).

### *Plasma lactate analyses*

Blood samples of 2 ml were put into tubes containing fluoride-oxalate anticoagulant. The tubes were kept in ice blocks for 15 min and then centrifuged at 3000 rpm at 4 °C for 5 min to separate plasma. Plasma lactate levels were determined in Rocher Cobas Mira Plus brand device (Lot number: W253088) (read at 556 nm wavelength) as mmol/l.

### *Statistical evaluations*

Mann Whitney *U* test was employed to determine the differences between groups. The comparison of measurements at different times within the group tested with two-way repeated measures analysis of variance, which arise from timing differences to determine whether the Bonferroni test was used. Level of significance was taken to be $p < 0.05$.

## Results

### *Pre-supplementation serum element levels of the groups (at rest and after exercise)*

Serum Mg, Ca, Fe, Cu, Se, P, and Zn levels measured before supplementation (at rest and post-exercise) were not different between groups 1 and 2 (Table 1). Likewise, there was no significant difference between serum Mg, Ca, Fe, Cu, Se, P, and Zn levels measured at rest in weeks 1, 2, 3, and 4 after supplementation in groups 1 and 2 (Table 1).

### *Post-supplementation serum element levels of the groups after exercise*

Serum Mg, Ca, Fe, Cu, Se, and Zn levels measured after exercise in the post-supplementation period in groups 1 and 2 were not different, whereas *p* level in group 1 was significantly higher than that in group 2 ($p < 0.05$, Table 1).

### *Comparison between pre- and post-zinc supplementation and pre- and post-exercise serum element levels*

Exercises both before and after zinc supplementation increased magnesium, calcium, iron, copper, selenium, phosphorus, and zinc levels in both groups 1 and 2, in comparison to the levels measured in pre-exercise periods ($p < 0.05$, Tables 2 and 3).

### *Comparison between the weekly changes caused by zinc supplementation in serum element levels in groups 1 and 2*

Zinc supplementation significantly elevated magnesium, calcium, iron, and zinc levels over the course of 4 weeks ($p < 0.05$, Tables 2 and 3).

On the other hand, zinc supplementation significantly reduced copper and selenium levels in one-week periods over the course of 4 weeks ($p < 0.05$), while it did not cause any change in phosphorus levels (Tables 2 and 3).

### *Comparison between plasma lactate values*

Pre-supplementation exercise increased plasma lactate levels ($p < 0.05$, Table 4), while exercise after zinc supplementation decreased plasma lactate ($p < 0.05$, Table 4).

## Discussion

### *Discussion of magnesium, calcium, and iron levels in the study groups*

Both exercise and zinc supplementation significantly elevated magnesium, calcium, and iron levels for 4 weeks.

Despite the presence of contradicting results (Lukaski, 2000), magnesium (mg), nerve transmission, muscle contraction, and in particular involved in the energy production of ATP is a mineral

**Table 1**
Serum Mg, Ca, Fe, Cu, Se, P, and Zn levels of the groups before supplementation, during supplementation, and after 4 weeks of zinc supplementation (rest and exercise).

| | Groups ($n$ = 10) | Mg (mg/dl) | Ca (mg/dl) | Fe (μg/dl) | Cu (μg/dl) | Se (μg/dl) | P (mg/dl) | Zn (μg/dl) |
|---|---|---|---|---|---|---|---|---|
| before supplementation pre- exercise | 1 | 1.66 ± 0.19 | 9.64 ± 0.60 | 71.35 ± 21.95 | 114.71 ± 17.33 | 10.15 ± 0.90 | 4.21 ± 0.43 | 74.68 ± 10.04 |
| | 2 | 1.65 ± 0.21 | 9.56 ± 0.84 | 74.44 ± 18.26 | 115.33 ± 25.80 | 8.77 ± 2.82 | 4.10 ± 0.76 | 72.90 ± 15.38 |
| | $p$ level | 0.65 | 0.940 | 0.623 | 0.970 | 0.054 | 0.273 | 0.450 |
| before supplementation post-exercise | 1 | 1.75 ± 0.18 | 9.91±0.54 | 82.57 ± 25.19 | 121.85 ± 19.92 | 11.11 ± 1.00 | 4.71 ± 0.45 | 80.58 ± 9.20 |
| | 2 | 1.70 ± 0.23 | 9.91±0.53 | 85.10 ± 22.25 | 128.55 ± 23.42 | 10.75 ± 1.47 | 4.71 ± 0.56 | 79.27 ± 15.94 |
| | $p$ level | 0.240 | 0.762 | 0.705 | 0.650 | 0.384 | 0.970 | 0.650 |
| weeks 1 after supplementation | 1 | 1.61 ± 0.21 | 9.26 ± 0.33 | 110.46 ± 11.66 | 82.50 ± 11.84 | 4.35 ± 2.23 | 4.33 ± 0.40 | 89.84 ± 7.56 |
| | 2 | 1.60 ± 0.25 | 9.14 ± 0.69 | 114.87 ± 12.28 | 83.62 ± 10.23 | 4.04 ± 1.73 | 4.23 ± 0.42 | 88.78 ± 18.32 |
| | $p$ level | 0.910 | 1.000 | 0.290 | 1.000 | 0.940 | 0.520 | 0.705 |
| weeks 2 after supplementation | 1 | 1.83 ± 0.21 | 9.64 ± 0.31 | 119.11 ± 15.79 | 82.40 ± 5.21 | 4.31 ± 1.30 | 4.44 ± 0.34 | 107.66 ± 10.88 |
| | 2 | 1.82 ± 0.21 | 9.39 ± 0.44 | 126.83 ± 12.44 | 82.11 ± 5.99 | 4.62 ± 1.44 | 4.38 ± 0.37 | 106.16 ± 19.35 |
| | $p$ level | 0.820 | 0.140 | 0.257 | 0.623 | 0.705 | 0.570 | 0.326 |
| weeks 3 after supplementation | 1 | 1.98 ± 0.19 | 10.30 ± 0.55 | 131.35 ± 16.71 | 86.43 ± 16.15 | 4.82 ± 1.95 | 4.58 ± 0.37 | 137.08 ± 12.27 |
| | 2 | 2.00 ± 0.16 | 10.24 ± 0.73 | 135.04 ± 14.44 | 80.42 ± 20.03 | 3.90 ± 1.14 | 4.47 ± 0.42 | 128.09 ± 25.32 |
| | $p$ level | 0.791 | 1.000 | 0.545 | 0.364 | 0.364 | 0.405 | 0.199 |
| weeks 4 after supplementation-before- exercise | 1 | 2.12 ± 0.15 | 10.54 ± 0.40 | 142.59 ± 16.77 | 79.78 ± 12.35 | 4.61 ± 1.66 | 4.66 ± 0.38 | 156.90 ± 16.85 |
| | 2 | 2.15 ± 0.33 | 10.90 ± 0.66 | 156.16 ± 21.70 | 80.37 ± 22.59 | 4.20 ± 2.17 | 4.58 ± 0.45 | 150.80 ± 22.66 |
| | $p$ level | 0.185 | 0.173 | 0.096 | 0.705 | 0.290 | 0.597 | 0.496 |
| after supplementation post- exercise | 1 | 2.37 ± 0.25 | 11.62 ± 0.60 | 158.94 ± 27.50 | 83.58 ± 10.64 | 5.79 ± 2.04 | 5.08 ± 0.16 | 165.83 ± 21.96 |
| | 2 | 2.29 ± 0.39 | 11.48 ± 1.03 | 165.05 ± 22.67 | 86.45 ± 28.86 | 4.84 ± 1.76 | 4.80 ± 0.46 | 148.63 ± 28.22 |
| | $p$ level | 0.623 | 0.650 | 0.597 | 0.880 | 0.406 | 0.031* | 0.199 |

* $p < 0.05$.

**Table 2**
Serum Mg, Ca, Fe, Cu, Se, P, and Zn levels of the group 1 in different timing before supplementation, during supplementation, and after 4 weeks of zinc supplementation (rest and exercise).

| Elements | Before supplementation pre- exercise | Before supplementation post-exercise | Weeks 1 after supplementation | Weeks 2 after supplementation | Weeks 3 after supplementation | Weeks 4 after supplementation before-exercise | Weeks 4after supplementation post-exercise |
|---|---|---|---|---|---|---|---|
| Mg (mg/dl) | 1.66 ± 0.19 **d** | 1.75 ± 0.18 **cd** | 1.61 ± 0.21 **d** | 1.83 ± 0.21 **c** | 1.98 ± 0.19 **c** | 2.12 ± 0.15 **b** | 2.37 ± 0.25 **a** |
| Ca (mg/dl) | 9.64 ± 0.60 **cd** | 9.91 ± 0.54 **cd** | 9.26 ± 0.33 **d** | 9.64 ± 0.31 **cd** | 10.30 ± 0.55 **b** | 10.54 ± 0.40 **b** | 11.62 ± 0.60 **a** |
| Fe (μg/dl) | 71.35 ± 21.95 **c** | 82.57 ± 25.19 **c** | 110.46 ± 11.66 **b** | 119.11 ± 15.79 **b** | 131.35 ± 16.71 **a** | 142.59 ± 16.77 **a** | 158.94 ± 27.50 **a** |
| Cu (μg/dl) | 114.71 ± 17.33 **a** | 121.85 ± 19.92 **a** | 82.50 ± 11.84 **b** | 82.40 ± 5.21 **b** | 86.43 ± 16.15 **b** | 79.78 ± 12.35 **b** | 83.58 ± 10.64 **b** |
| Se (μg/dl) | 10.15 ± 0.90 **b** | 11.11 ± 1.00 **a** | 4.35 ± 2.23 **c** | 4.31 ± 1.30 **c** | 4.82 ± 1.95 **c** | 4.61 ± 1.66 **c** | 5.79 ± 2.04 **c** |
| P (mg/dl) | 4.21 ± 0.43 **b** | 4.71 ± 0.45 **ab** | 4.33 ± 0.40 **b** | 4.44 ± 0.34 **ab** | 4.58 ± 0.37 **a** | 4.66 ± 0.38 **a** | 5.08 ± 0.16 **a** |
| Zn (μg/dl) | 74.68 ± 10.04 **e** | 80.58 ± 9.20 **e** | 89.84 ± 7.56 **d** | 107.66 ± 10.88 **c** | 137.08 ± 12.27 **b** | 156.90 ± 16.85 **a** | 165.83 ± 21.96 **a** |

a, b, c, d, e: There is significant difference between means of the same parameter with a different superscripted letter the same line ($P < 0.05$).

participating in more than 300 enzymatic reactions, thereafter, magnesium has critical effects on muscle strength and metabolism (Finstad et al., 2001). Duma et al. (1998) showed that exercise increased serum magnesium in runners. Elevated magnesium levels we obtained following exercise both before and after 4-week zinc supplementation in our study are parallel to the results of Duma et al. (1998). In the present study, serum magnesium levels in both groups decreased at the end of week 1 of zinc supplementation, but then increased in weeks 2–4. Results of the study reporting that reduced serum magnesium levels in diabetic rats subjected to acute swimming exercise were restored after zinc supplementation (Bicer et al., 2011) are parallel to ours. Molina-López et al. (2012) also showed that the correlation between erythrocyte magnesium and zinc. What needs emphasis here is that magnesium levels in both groups increased as of week 2 of zinc supplementation. This is an original result suggesting that in order for the magnesium-elevating effect of zinc to appear, a supplementation period of at least 2 weeks is necessary.

It was reported that calcium levels in marathon runners were not different from those levels in the controls (Crespo et al., 1995), while Duma et al. (1998) demonstrated that medium- and long-distance running exercise increased serum calcium. The latter is an important result supporting the increased calcium levels we found in exercise before and after supplementation. There is a critical relation between zinc and calcium (Contreras et al., 2002; Fushimi et al., 1993; Sunar et al., 2009). Zinc deficiency causes inadequate calcium absorption (O'Dell et al., 1997), while zinc supplementation increases 1,25 dihydroxycholecalciferol synthesis (Kimmel et al., 1991). In this

**Table 3**
Serum Mg, Ca, Fe, Cu, Se, P, and Zn levels of the group 2 in different timing before supplementation, during supplementation, and after 4 weeks of zinc supplementation (rest and exercise).

| Elements | Before supplementation pre- exercise | Before supplementation post-exercise | Weeks 1 after supplementation | Weeks 2 after supplementation | Weeks 3 after supplementation | Weeks 4 after supplementation before-exercise | Weeks 4 after supplementation post-exercise |
|---|---|---|---|---|---|---|---|
| Mg (mg/dl) | 1.65 ± 0.21 **c** | 1.70 ± 0.23 **bc** | 1.60 ± 0.25 **c** | 1.82 ± 0.21 **b** | 2.00 ± 0.16 **ab** | 2.15 ± 0.33 **ab** | 2.29 ± 0.39 **a** |
| Ca (mg/dl) | 9.56 ± 0.84 **bc** | 9.91 ± 0.53 **bc** | 9.14 ± 0.69 **c** | 9.39 ± 0.44 **bc** | 10.24 ± 0.73 **b** | 10.90 ± 0.66 **a** | 11.48 ± 1.03 **a** |
| Fe (μg/dl) | 74.44 ± 18.26 **d** | 85.10 ± 22.25 **d** | 114.87 ± 12.28 **c** | 126.83 ± 12.44 **b** | 135.04 ± 14.44 **b** | 156.16 ± 21.70 **ab** | 165.05 ± 22.67 **a** |
| Cu (μg/dl) | 115.33 ± 25.80 **ab** | 128.55 ± 23.42 **a** | 83.62 ± 10.23 **bc** | 82.11 ± 5.99 **c** | 80.42 ± 20.03 **c** | 80.37 ± 22.59 **c** | 86.45 ± 28.86 **bc** |
| Se (μg/dl) | 8.77 ± 2.82 **a** | 10.75 ± 1.47 **a** | 4.04 ± 1.73 **b** | 4.62 ± 1.44 **b** | 3.90 ± 1.14 **b** | 4.20 ± 2.17 **b** | 4.84 ± 1.76 **b** |
| P (mg/dl) | 4.10 ± 0.76 **c** | 4.71 ± 0.56 **a** | 4.23 ± 0.42 **bc** | 4.38 ± 0.37 **b** | 4.47 ± 0.42 **ab** | 4.58 ± 0.45 **ab** | 4.80 ± 0.46 **a** |
| Zn (μg/dl) | 72.90 ± 15.38 **d** | 79.27 ± 15.94 **d** | 88.78 ± 18.32 **d** | 106.16 ± 19.35 **c** | 128.09 ± 25.32 **b** | 150.80 ± 22.66 **a** | 148.63 ± 28.22 **a** |

a, b, c, d: There is significant difference between means of the same parameter with a different superscripted letter the same line ($P < 0.05$).

**Table 4**
Level of significance of the changes in plasma lactate levels of athletes observed over the course of the study.

| Parameter | Groups ($n = 10$) | before supplementation pre-exercise | before supplementation post-exercise | weeks 4 after supplementation before- exercise | weeks 4 after supplementation post-exercise |
|---|---|---|---|---|---|
| Plasma lactate (mmol/L) | 1 | 1.78 ± 0.64 **b** | 8.26 ± 1.86 **a** | 0.95 ± 0.18 **c** | 6.95 ± 1.27 **a** |
| | 2 | 1.98 ± 0.93 **c** | 9.79 ± 2.13 **a** | 1.13 ± 0.41 **c** | 6.78 ± 1.59 **b** |

a, b, c: There is significant difference between means of the same parameter with a different superscripted letter the same line ($P < 0.05$).

study, both doses of zinc supplementation restored the calcium levels which dropped in Week 1 to resting values in Week 2. Calcium levels in Weeks 3 and 4 were found significantly elevated in comparison to resting values. Zinc has critical effects on calcium metabolism, and consequently, on the structure and development of bone tissue (Ma and Yamaguchi, 2001). The results of the researchers cited above are in agreement with increased calcium levels we found after zinc supplementation.

It was reported that serum iron levels significantly increased after the run in marathon runners (Buchman et al., 1998), and similarly, that plasma iron showed a remarkable increase after high-intensity endurance training in bicyclists (Dressendorfer et al., 2002). In the same vein, serum iron was shown to increase after 60-min running exercise in trained medium-level athletes (Peeling et al., 2009) and plasma iron was found to rise in female swimmers following swimming exercise (Lukaski et al., 1990). These reports lend significant support to the elevated serum iron values obtained after exercise in the present study. The results of the study demonstrate that, when compared to resting values, zinc supplementation brought about significant increases in serum iron in one-week periods over the course of 4 weeks. It was noted that knowledge of the interaction between dietary zinc and other elements was important for athlete health and performance, as excess iron intake could lead to zinc deficiency (McDonald and Keen, 1988). Supplementation of 22 mg oral zinc to male football players for 12 weeks significantly reduced plasma iron (Oliveira et al., 2009). This result is in contradiction to the elevated serum iron levels we found with zinc supplementation. However, in the concerned study, zinc supplementation to the athlete group was continued for 12 weeks. The contradiction may be attributed to the differences in duration and/or dose of supplementation. As Cordova et al. (1993) stated, 200 ppm oral zinc support elevated serum iron in rats. This report is consistent with the increased serum iron levels we found after zinc supplementation in the present study.

*Discussion of copper, selenium, and phosphorus levels in the study groups*

Exercise before and after zinc supplementation resulted in increased copper, selenium, and phosphorus levels. Zinc supplementation significantly reduced copper and selenium, but did not change phosphorus in one-week periods over the course of 4 weeks.

It was shown that plasma copper values increased after physical activity in female swimmers (Lukaski et al., 1990), and also that high-intensity endurance training brought about a marked increase in plasma copper in male bicyclists (Dressendorfer et al., 2002). Anderson et al. (1995) reported that acute exercise significantly elevated serum copper in both athletes and sedentary individuals. Consequently, the results of the studies about the relation between exercise and copper demonstrate increases in serum copper levels after exercise and this is consistent with the elevated serum copper levels we found after exercise in the present study. Zinc supplementation in both group 1 and group 2 significantly reduced copper levels in one-week periods over 4 weeks, in comparison to the resting values. It was already suggested that there was a negative correlation between body zinc and copper levels (Kilic, 2007). Oral zinc supplementation was reported be able to affect copper absorption in a period of 24 h, while chronic zinc support at a dose of 50 mg/day was shown to be capable of causing copper deficiency (Fischer et al., 1984). Similarly, 22 mg/day zinc gluconate support to bicyclists for 22 days caused a significant drop in plasma copper levels (Marques et al., 2011). Reduced serum copper found after zinc supplementation in this study is parallel to the reports of the cited researchers.

Selenium is known to be necessary for a variety of metabolic processes including thyroid hormone metabolism, protection against oxidative stress, and immunity functions (Akil et al., 2011). Physical exercise causes re-distribution of elements between body reserves, blood and tissues (Bordin et al., 1993).

Thus, exhaustion exercise is expected to alter element levels. The report that acute swimming exercise significantly elevated serum selenium levels in rats (Bicer et al., 2011) lends important support to the increases identified in selenium levels after exercise. In the present study, zinc supplementation markedly lowered selenium levels in one week periods over 4 weeks, relative to resting selenium values. There are a limited number of studies exploring the relation between zinc and selenium. Bicer et al. (2011) reported that the increases caused by acute swimming exercise in serum selenium levels were prevented by 4-week zinc supplementation. The results of the concerned study support, though indirectly, the reduced selenium levels established after zinc supplementation.

Exercise before and after zinc supplementation increased serum phosphorus values in this study. This result is consistent with the study which showed that acute swimming exercise significantly increased plasma phosphorus (Baltaci et al., 2009). The results of this study also revealed that 4-week zinc support did not affect serum phosphorus levels. In fact, it was reported that 6 mg/kg/day intraperitoneal zinc supplementation to rats for 4 weeks did not bring about a remarkable change in serum phosphorus levels, in comparison to control values (Bicer et al., 2011). The results of the cited study are parallel to the results of this study.

*Discussion of zinc values in the study groups*

Exercise before and after 220 mg/day zinc supplementation was found to significantly elevate serum zinc levels, while exercise following 440 mg/day zinc supplementation caused a decrease in zinc levels. Short-term high-intensity exercise (Ohno et al., 1985) and marathon run (Marrella et al., 1993) were both shown to increase plasma zinc. Increased plasma zinc levels caused by exercise were reported by other researchers as well (Cordova and Navas, 1998; Mundie and Hare, 2001). Serum zinc increase found after exercise in the present study is parallel to the results of the researchers cited above. Interestingly, exercise after 440 mg/day zinc supplementation reduced serum zinc levels. This can probably be explained by increased excretion of zinc from the digestive system. It is known that the activities of zinc transporters (ZnT) ZnT1, ZnT4, and ZnT5 which enable zinc absorption in the digestive system increase in lower zinc levels to increase zinc absorption in the small intestines and conversely that these transporters are suppressed in higher zinc levels to increase the excretion of zinc from the digestive system (McMahon and Cousins, 1998). Zinc supplementation periodically elevated serum zinc levels in one-week periods over the course of 4 weeks in both groups, in comparison to resting zinc levels. Zinc support to both athletes and exercised experimental animals was shown to result in increased serum zinc levels (Baltaci et al., 2013; Kara et al., 2010; Kilic et al., 2006). Thus, increased serum zinc levels resulting from zinc supplementation may be considered an expected result and lend support to the results of the researchers cited above.

*Discussion of the lactate values in the study groups*

Pre-supplementation exercise increased plasma lactate levels, while zinc supplementation reduced plasma lactate. Elevated lactate values may be seen as an expected result after intense exercise. Similar results were obtained with post-supplementation exercise. In other words, exercise to exhaustion elevated plasma lactate levels after the supplementation as well. Plasma lactate quantified at rest and after exercise in the post-supplementation period was found significantly lower than the lactate values measured at rest and after exercise in the pre-supplementation period. In other words, zinc support reduced plasma lactate. This critical finding suggests that zinc supplementation may delay muscle tiredness in physical activity. It was noted that daily and continuous exercise could be responsible for the impairments in the zinc metabolism in athletes and those impairments and zinc loss could cause muscle tiredness and weakness (Cordova and Alvarez-Mon, 1995). Reduced serum zinc concentration observed in athletes was reported to result in a decrease in the muscle zinc concentration (Cordova and Alvarez-Mon, 1995; Cordova and Navas, 1998). As zinc is required for several enzymes involved in the metabolism, severe zinc deficiency will have a negative impact on muscle functions (Cordova and Alvarez-Mon, 1995; Cordova and Navas, 1998). In a previous study, 5 healthy males in the 23–57 age range were fed on a normal zinc diet for 30 days, then on a zinc-deficient diet for 120 days, and lastly on a zinc-supplemented diet for 30 days, consecutively (Lukaski et al., 1984). Aerobic capacity was periodically determined in each diet. Relative zinc balance decreased during zinc deficiency and pre- and post-exercise zinc levels were found lower (Lukaski et al., 1984). However, zinc balance increased during zinc supplementation and both plasma zinc levels and haematocrit rates were found higher in the post-exercise period (Lukaski et al., 1984). Similarly, gastrocnemius muscles of rats fed on a zinc-supplemented diet were reported to tire later in comparison to controls (Richardson and Drake, 1979). Furthermore, muscle development and muscle DNA concentration in the rats which were fed on a severely zinc-deficient diet were found to decrease (Park et al., 1986). Twelve professional football players were subjected to maximum exercise on an ergometer and it was shown that the subjects had lower serum zinc levels after the exercise, those with lower serum zinc levels also had higher plasma lactate levels and developed hypoglycemia (Khaled et al., 1997). This interesting piece of information may stimulate further research into the effects of zinc, which is an important trace element, on physiological performance. An overall assessment of the data presented above suggests that zinc has critical effects on muscle functions and therefore, it can delay muscle tiredness. It was reported in a study by Baltaci et al. (2003) that plasma lactate levels which were elevated in zinc deficiency in rats subjected to an acute swimming exercise were reduced by zinc supplementation. This is a significant result for research into zinc and tiredness relationship and is consistent with reduced lactate levels obtained with zinc supplementation.

The results of present study show that 4 weeks zinc supplementation delay tiredness exhaustion by regulate elements metabolism. Zinc supplementtaion may has useful on sportive performance.

## Acknowledgements

Zinc sulfate capsules were supplied by Berko Drug and Chemicals Industry Inc.

## References

Akil, M., Bicer, M., Menevse, E., Baltaci, A.K., Mogulkoc, R., 2011. Selenium supplementation prevents lipid peroxidation caused by arduous exercise in rat brain tissue. Bratisl. Med. J. Bratisl. Lek. Listy 112, 314–317.

Anderson, R.A., Bryden, N.A., Polansky, M.M., Deuster, P.A., 1995. Acute exercise effects on urinary losses and serum concentrations of copper and zinc of moderately trained and untrained men consuming a controlled diet. Analyst 120, 867–870.

Baltaci, A.K., Ozyurek, K., Mogulkoc, R., Kurtoglu, E., Oztekin, E., 2003. Effects of zinc deficiency and supplementation on some hematologic parameters of rats performing acute swimming exercise. Acta Physiol. Hung. 90, 25–32.

Baltaci, A.K., Sunar, F., Mogulkoc, R., Oztekin, E., 2004. The effects of zinc deficiency and supplementation on lipid peroxidation in bone tissue of ovariectomized rats. Toxicology 203, 77–82.

Baltaci, A.K., Uzun, A., Kilic, M., Mogulkoc, R., 2009. Effects of acute swimming exercise on some elements in rats. Biol. Trace Elem. Res. 127, 148–153.

Baltaci, A.K., Ozyurek, K., Mogulkoc, R., Kurtoglu, E., Ozkan, Y., Celik, I., 2013. Effects of zinc deficiency and supplementation on the glycogen contents of liver and plasma lactate and leptin levels of rats performing acute exercise. Biol. Trace Elem. Res. 96, 227–236.

Baltaci, A.K., Sunar, F., Mogulkoc, R., Acar, M., Toy, H., 2014. The effect of zinc deficiency and zinc supplementation on element levels in the bone tissue of ovariectomized rats: histopathologic changes. Arch. Physiol. Biochem. 120, 80–85.

Bicer, M., Akil, M., Sivrikaya, A., Kara, E., Baltaci, A.K., Mogulkoc, R., 2011. Effect of zinc supplementation on the distribution of various elements in the serum of diabetic rats subjected to an acute swimming exercise. J. Physiol. Biochem. 67, 511–517.

Bicer, M., Gunay, M., Baltaci, A., K, Uney, K., Mogulkoc, R., Akil, M., 2012. Effect of zinc supplementation on lipid peroxidation and lactate levels in rats with diabetes induced by streptozotocin and subjected to acute swimming exercise. Bratisl. Lek. Listy 113, 199–205.

Bordin, D., Sartorelli, L., Bonanni, G., Mastrogiacomo, I., Scalco, E., 1993. High intensity physical exercise induced effects on plasma levels of copper and zinc. Biol. Trace Elem. Res. 36, 129–134.

Buchman, A.L., Keen, C., Commisso, J., Killip, D., Ou, C.N., Rognerud, C.L., et al., 1998. The effect of a marathon run on plasma and urine mineral and metal concentrations. J. Am. Coll. Nutr. 17, 124–127.

Contreras, F., Simonovis, N., Fovilioux, C., Bolivar, A., Cavella, J.L., Lezama, E., et al., 2002. Zincuria and zincemia in postmenopausal oeteoporosis Postmemaposal osteophoroz. Int. Congr. Ser. 1237, 219–229.

Cordova, A., Alvarez-Mon, M., 1995. Behaviour of zinc in physical exercise: a special reference to immunity and fatigue. Neurosci. Biobehav. Rev. 19, 439–445.

Cordova, A., Navas, F.J., 1998. Effect of training on zinc metabolism: changes in serum and sweat zinc concentrations in sportsmen. Ann. Nutr. Metab. 42, 274–282.

Cordova, A., Navas, F.J., Escanero, J.F., 1993. The effect of exercise and zinc supplement on the hematological parameters in rats. Biol. Trace Elem. Res. 39, 13–20.

Couzy, F., Lafargue, P., Guezennec, C.Y., 1990. Zinc metabolism in the athlete: influence of training nutrition and other factors. Int. J. Sports Med. 11, 263–266.

Crespo, R., Relea, P., Lozano, D., Macarro-Sanchez, M., Usabiaga, J., Villa, L.F., et al., 1995. Biochemical markers of nutrition in elite-marathon runners. J. Sports Med. Phys. Fit. 35, 268–272.

Dressendorfer, R.H., Petersen, S.R., Lovshin, S.E., Keen, C.L., 2002. Mineral metabolism in male cyclists during high-intensity endurance training. Int. J. Sport Nutr. Exerc. Metab. 12, 63–72.

Duchateau, J., Delespesse, G., Vereecke, P., Collet, H., 1981. Influence of oral zinc supplementation on the lymphocyte response to mitogens of normal subjects. Am. J. Clin. Nutr. 34, 88–93.

Duma, E., Orbai, P., Derevenco, P., 1998. Blood levels of some electrolytes and hormones during exercise in athletes. Rom. J. Physiol. 35, 55–60.

Eskici, G., Gunay, M., Baltaci, A.K., Mogulkoc, R., 2016. The effect of zinc supplementation on the urinary excretion of elements in female athletes. Pak. J. Pharm. Sci. 29, 125–129.

Finstad, E.W., Newhouse, I.J., Lukaski, H.C., Mcauliffe, J.E., Stewart, C.R., 2001. The effects of magnesium supplementation on exercise performance. Med. Sci. Sports Exerc. 33, 493–498.

Fischer, P.W., Giroux, A., L'Abbé, M.R., 1984. Effect of zinc supplementation on copper status in adult man. Am. J. Clin. Nutr. 40, 743–746.

Fushimi, H., Inoue, T., Yamada, Y., Horie, H., Kameyama, M., Minami, T., et al., 1993. Zinc deficiency exaggerates diabetic osteoporosis. Diabetes Res. Clin. Pract. 20, 191–196.

Gunay, M., Tamer, K., Cicioglu, I., 2006. Spor Fizyolojisi ve Performans Olcumu, 1st ed. Gazi Kitabevi, Ankara, Turkey.

Haralambie, G., 1981. Serum zinc athletes in training. Int. J. Sports Med. 2, 135–138.

Kara, E., Gunay, M., Cicioglu, I., Ozal, M., Kilic, M., Mogulkoc, R., et al., 2010. Effect of zinc supplementation on antioxidant activity in young wrestlers. Biol. Trace Elem. Res. 134, 55–63.

Khaled, S., Brun, J.F., Bardet, L., Cassanas, G., 1997. Physiological importance of zinc in muscular activity. Sci. Sports 12, 179–191.

Khaled, S., Brun, J.F., Cassanas, G., Bardet, L., Orsetti, A., 1999. Effects of zinc supplementation on blood rheology during exercise. Clin. Hemorheol. Microcirc. 20, 1–10.

Kilic, M., Baltaci, A.K., Gunay, M., Gökbel, H., Okudan, N., Cicioglu, I., 2006. The effect of exhaustion exercise on thyroid hormones and testosterone levels of elite athletes receiving oral zinc. Neuro Endocrinol. Lett. 27, 247–252.

Kilic, M., 2007. Effect of fatiguing bicycle exercise on thyroid hormone and testosterone levels in sedentary males supplemented with oral zinc. Neuro Endocrinol. Lett. 28, 681–685.

Kimmel, P.L., Watkins, D.W., Gubish, C.T., Slatopolsky, E., Langman, C.B., 1991. Zinc nutritional status modulates the 1,25-(OH)2D. Response in uremic rats. Miner. Electrol. Metab. 17, 307–314.

Lukaski, H.C., Bolonchuk, W.W., Klevay, L.M., Milne, D.B., Sandstead, H.H., 1984. Changes in plasma zinc content after exercise in men fed a low-zinc diet. Am. J. Physiol. 247, 88–93.

Lukaski, H.C., Hoverson, B.S., Gallagher, S.K., Bolonchuk, W.W., 1990. Physical training and copper, iron, and zinc status of swimmers. Am. J. Clin. Nutr. 51, 1093–1099.

Lukaski, H.C., 2000. Magnesium, zinc, and chromium nutriture and physical activity. Am. J. Clin. Nutr. 72, 585–593.

Ma, Z.J., Yamaguchi, M., 2001. Role of endogenous zinc in the enhancement of bone protein synthesis associated with bone growth of newborn rats. J. Bone Miner. Metab. 19, 38–44.

Marques, L.F., Donangelo, C.M., Franco, J.G., Pires, L., Luna, A.S., Casimiro-Lopes, G., et al., 2011. Plasma zinc, copper, and serum thyroid hormones and insulin levels after zinc supplementation followed by placebo in competitive athletes. Biol. Trace Elem. Res. 142, 415–423.

Marrella, M., Guerrini, F., Solero, P.L., Tregnaghi, P.L., Schena, F., Velo, G.P., 1993. Blood copper and zinc changes in runners after a marathon. J. Trace Elem. Electrol. Health Dis. 7, 248–250.

McDonald, R., Keen, C.L., 1988. Iron, zinc and magnesium nutrition and athletic performance. Sports Med. 5, 171–184.

McMahon, R.J., Cousins, R.J., 1998. Regulation of the zinc transporter ZnT-1 by dietary zinc. Proc. Natl. Acad. Sci. 95, 4841–4846.

Molina-López, J., Molina, J.M., Chirosa, L.J., Florea, D., Sáez, L., Millán, E., Planells, E., 2012. Association between erythrocyte concentrations of magnesium and zinc in high-performance handball players after dietary magnesium supplementation. Magnes. Res. 25, 79–88.

Mundie, T.G., Hare, B., 2001. Effects of resistance exercise on plasma, erythrocyte, and urine Zn. Biol. Trace Elem. Res. 79, 23–28.

O'Dell, B.L., Emery, M., Xia, J., Browning, J.D., 1997. In vitro addition of glutathione to blood from zinc-deficient rats corrects platelet defects: impaired aggregation and calcium uptake. J. Nutr. Biochem. 8, 346–350.

Ohno, H., Yamashita, K., Doi, R., Yamamura, K., Kondo, T., Taniguchi, N., 1985. Exercise- induced changes in blood zinc and related proteins in humans. J. Appl. Physiol. 58, 1453–1458.

Oliveira, K.J.F., Donangelo, C.M., Oliveira, A.V., Silveira, C.L.P., Koury, J.C., 2009. Effect of zinc supplementation on the antioxidant, copper, and iron status of physically active adolescents. Cell Biochem. Funct. 27, 162–166.

Park, J.H., Grandjean, C.J., Antonson, D.L., Vanderhoof, J.A., 1986. Effects of isolated zinc deficiency on the composition of skeletal muscle, liver and bone during growth in rats. J. Nutr. 116, 610–617.

Peeling, P., Dawson, B., Goodman, C., Landers, G., Wiegerinck, E.T., Swinkels, D.W., et al., 2009. Effects of exercise on hepcidin response and iron metabolism during recovery. Int. J. Sport Nutr. Exerc. Metab. 19, 583–597.

Prasad, A.S., 1985. Clinical manifestations of zinc deficiency. Annu. Rev. Nutr. 5, 341–363.

Prasad, A.S., 2009a. Impact of the discovery of human zinc deficiency on health. J. Am. Coll. Nutr. 28, 257–265.

Prasad, A.S., 2009b. Zinc: role in immunity, oxidative stress and chronic inflammation. Curr. Opin. Clin. Nutr. Metab. Care 12, 646–652.

Prasad, A.S., 2013. Discovery of human zinc deficiency: its impact on human health and disease. Adv. Nutr. 4, 176–190.

Richardson, J.H., Drake, P.D., 1979. The effects of zinc on fatigue of striated muscle. J. Sports Med. Phys. Fit. 19, 133–134.

Sivrikaya, A., Bicer, M., Akil, M., Baltaci, A.K., Mogulkoc, R., 2012. Effects of zinc supplementation on the element distribution in kidney tissue of diabetic rats subjected to acute swimming. Biol. Trace Elem. Res. 147, 195–199.

Sunar, F., Baltaci, A.K., Ergene, N., Mogulkoc, R., 2009. Zinc deficiency and supplementation in ovariectomized rats: their effect on serum estrogen and progesterone levels and their relation to calcium and phosphorus. Pak. J. Pharm. Sci. 22, 150–154.

Vallee, B.L., Falchuk, K.H., 1993. The biochemical basis of zinc physiology. Physiol. Rev. 73, 79–118.