α-Lipoic Acid Therapy Modulates Serum Levels of Some Trace Elements and Antioxidants in Type 2 Diabetic Patients

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Abstract: Problem statement: The metabolism of several trace elements has been reported to alter in diabetes mellitus. The disturbance of their serum levels may have a role in the pathogenesis and progress of this disease. In addition, the reports about the status of antioxidants and antioxidant enzymes in diabetic patients are very contradictory. Though α-Lipoic Acid (LA) has long been touted as antioxidant, it has also been shown to improve glucose handling. Approach: The present study aimed to investigate the effect of exogenous supplementation of LA (600mg day⁻¹) on the serum levels of some antioxidants (Superoxide Dismutase (SOD), Glutathione (GSH) and vitamin C) and trace elements (Zn, Se, Cu and Co) in type 2 diabetic patients. The aim of this study was also extended to study the association of these parameters with the glycemic status. The studied participants were categorized into 3 groups (15 each): Control group: Non diabetic healthy volunteers. Diabetic group: Type 2 diabetic patients. Lipoic acid treated group: Type 2 diabetic patients received α-lipoic acid for 2 months in a daily oral dose of 600 mg. All participants were subjected to full history taking and complete clinical examination during the experimental period. Fasting serum samples were taken for determination of glucose, insulin, lipid profile and antioxidants as well as some trace elements. Homeostasis Model Assessment (HOMA) was also calculated as a marker of insulin resistance. Results: The results revealed that LA improved insulin resistance present in diabetic patients. The effects of oral treatment with LA were pronounced by improvement of serum levels of antioxidants (SOD and GSH, p<0.001, while vitamin C, p<0.02), Zn and Se (amounted 24.17 and 23.24%, respectively), compared to diabetic group. Oral treatment with LA produced strong positive correlations between serum levels of fasting glucose and both SOD and Se (r = 0.8). In addition, LA converted the negative correlation between SOD and HOMA index in diabetic patients into strong positive correlation. Conclusion: This study suggests that oral administration of LA (600mg day⁻¹) for 2 months to type 2 diabetic patients alleviated the insulin resistance, oxidative stress and lipid profile abnormalities. In addition, LA returned the serum levels of Zn and Se to the normal values.

Key words: α-Lipoic acid, trace elements, superoxide dismutase, glutathione, Diabetes Mellitus (DM) and Homeostasis Model Assessment (HOMA)

INTRODUCTION

Diabetes Mellitus (DM) is one of the most common chronic diseases in nearly all countries and continues to increase in numbers and significance (Shaw et al., 2010). Diabetes is not simply a disorder of glucose homeostasis but is also accompanied by various degenerative manifestations such as accelerated aging, cardiovascular disease and microvascular lesions leading to retinopathy, neuropathy and glomerulopathy. These events may be related to the hyperproduction of free radicals and to a dysfunction of biological antioxidant systems such as low enzyme activity or deficient micronutrient status (Faure et al., 1993). Oxidative stress is increased in diabetes mellitus owing to an increase in the production of oxygen free radicals, such as super oxide (O₂⁻), hydrogen peroxide (H₂O₂) and hydroxide (OH⁻) radicals and deficiency in antioxidant defense mechanisms. Increased non-enzymatic and autooxidative glycosylation is one of the
possible mechanisms that contribute to the formation of free radicals and free radical-induced lipid peroxidation in diabetes mellitus (Hunt et al., 1990).

The reports about the status of antioxidants and antioxidant enzymes in diabetic patients are very contradictory, both increases and decreases of antioxidant activity have been reported (Soliman, 2008).

There is accumulating evidence that the metabolism of several trace elements is altered in DM and these nutrients might have specific roles in the pathogenesis and progress of this disease (Kamal et al., 2009).

Alpha-lipoic acid (LA, thioctic acid) is synthesized in liver and other tissues, acts as a co-factor in a multi-enzyme dehydrogenase complex. There is growing evidence that orally supplied lipoic acid may not be used as a metabolic cofactor but instead, elicits a unique set of biochemical activities with potential pharmacotherapeutic value against a host of patho-physiologic insults. It is used clinically for treatment of diabetic neuropathy (Shay et al., 2009).

While beneficial roles for LA and its reduced form (DHLA) in augmenting antioxidant defenses have been well characterized, much less is known about their potential role in modulating trace element status in vivo. The present study was undertaken to investigate the effect of exogenous supplementation of Lipoic acid on the serum levels of some trace elements (Zn, Cu, Co and Se) and some antioxidants in type 2 diabetic patients. The aim of this study also was extended to study the association of these parameters with the glycemic status.

MATERIALS AND METHODS

The current study included 45 Egyptian males: 30 diabetic patients, who were attending the outpatient clinics of National Research Center, El-Dokki health insurance policlinic, Cairo, Egypt, their ages ranged from 40-55 years (46.6±7.94) with Body Mass Index (BMI) 30.02±1.85 Kg m⁻². In addition, 15 age and sex matched healthy volunteers (BMI 28.74±2.43 Kg m⁻²) were included. Written consent was obtained from all participants who were fully informed of the purpose of the study. All participants were subjected to full history taking and complete clinical examination throughout the study which extended for 2 months.

The diagnosis of type 2 DM was based on the criteria of the Expert Committee on the Diagnosis and Classification of Diabetes Mellitus (2002). Duration of DM ranged from 3-8 years (4.13±1.41). ALL patients were on metformin in a dose 2000 mg day⁻¹ and glimepiride in a dose of 2-3 mg day⁻¹. Diabetic patients were not taking any medicines other than oral anti-diabetic drugs. Special stress was given to vitamin, mineral supplements, thyroid hormones, estrogen, progesterone, diuretics, or antihypertensive agents. No history of any recent acute illness or clinical evidence suggestive of kidney, liver or other endocrine diseases. Patients with diabetic complications (retinopathy, symptomatic neuropathy, nephropathy and vascular diseases) were also excluded.

The studied participants were categorized into 3 groups: Control group (Control) comprising 15 non-diabetic, age and sex matched apparently healthy volunteers. Diabetic group (Diabetic) comprising 15 type 2 diabetic patients. Lipoic acid treated group (Diabetic + LA)/diabetic patients (n = 15) who were convinced to receive α-lipoic acid for 2 months in a daily oral dose of 600 mg.

From all subjects, fasting blood samples were drawn. A part of blood sample was taken on EDTA as whole blood sample and another part was taken on a plain tube without anticoagulant for separation of serum by centrifugation at 3000 rpm for 10 min

Serum glucose level was assayed by glucose oxidase method (Barham and Trinder, 1972). Levels of serum insulin were assayed by ELISA (Dhahir et al., 1992). Homeostasis Model Assessment (HOMA), which correlates positively with insulin-resistance, was calculated according to Mahfouz et al. (2010). Triacylglycerol (TG) was assayed by peroxidase coupled method of Jacobs and Van Denmark (1960) and High Density Lipoprotein-Cholesterol (HDL-C) by the enzymatic method after precipitation of other lipoproteins with MgCl₂ and dextran sulphate according to the method of Finley (1978). Low Density Lipoprotein-Cholesterol (LDL-C) was assayed by the enzymatic method after precipitation of the LDL fraction by polystyrene sulphate according to the method of Kerscher et al. (1985) while Very Low Density Lipoprotein-Cholesterol (VLDL-C) was calculated according to Freidwald et al. (1972). Serum total superoxide dismutase activity (SOD) was determined according to the method of Maier and Chan (2002), while serum glutathione was determined by enzymatic colorimetric method described by Onyango and Khan (2006). Determination of the serum level of vitamin C was performed according to the method of Jagota and Dani (1982). Serum levels of trace elements (Zn, Cu, Co and Se) were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Agilent 7500ce, Japan).

Statistical analysis: All results were expressed as the mean ± Standard Error (SE). Statistical analysis was performed with Statistical Package for the Social Science for Windows (SPSS, version 13.0, Chicago, IL, USA). Comparison of different variables in various
**RESULTS**

Data presented in Table 1, illustrate that glucose homeostatic parameters (fasting serum glucose, insulin and HOMA) studied in both groups; diabetic untreated and diabetic treated with lipoic acid, were significantly (p<0.0001) elevated, compared to control group. Non significant improvement in serum level of glucose was observed in LA treated group, compared to diabetic group. However, administration of lipoic acid improved significantly the values of insulin and HOMA index (p<0.001 and 0.02, respectively), compared to diabetic untreated group.

The studied lipid profile parameters showed significant elevations in the serum levels of triacylglycerol, LDL-C and VLDL-C in both diabetic groups, compared to normal control group. Serum level of HDL-c showed significant reduction (p<0.001) in untreated and treated diabetic groups, compared to control group. On the other hand, significant reductions (p<0.03) in the serum levels of TG and VLDL-c were observed in Lipoic treated group, compared to diabetic untreated group.

The levels of serum antioxidants and trace elements are shown in Table 2. Significant reductions were noticed in the serum levels of all the antioxidant parameters (p<0.0001) in diabetic group, compared to control group. Lipoic acid group showed no significant changes in the serum levels of SOD and GSH, while vitamin C level showed significant reduction (p<0.02), compared to control group. Exogenous supplementation of Lipoic acid improved significantly the studied parameters, (p<0.001, except for vitamin C, p<0.02) compared to diabetic group. Significant reduction in the serum level of Zn (p<0.0001) was observed in diabetic group, while serum level of Se was no significant compared to control group. Treatment with Lipoic acid improved significantly the serum levels of Zn and Se (amounted 24.17 and 23.24%, respectively), compared to untreated diabetic group.

In regard to serum levels of Cu and Co, lipoic acid administration did not affect their levels. Cu was significantly elevated (p<0.0001) while Co level did not change in both diabetic groups as compared to control group.

### Table 1: Serum levels of glucose homeostatic parameters, TG and lipoproteins-C in the different studied groups (Means ± SE)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>Diabetic</th>
<th>Diabetic + LA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (mg dL⁻¹)</td>
<td>76.20±1.19</td>
<td>167.00±14.60</td>
<td>163.20±9.99</td>
</tr>
<tr>
<td>Insulin (µIU mL⁻¹)</td>
<td>7.03±0.24</td>
<td>20.16±0.44</td>
<td>14.00±0.41</td>
</tr>
<tr>
<td>HOMA index</td>
<td>1.33±0.05</td>
<td>8.40±0.80</td>
<td>5.69±0.40</td>
</tr>
<tr>
<td>TG (mg dL⁻¹)</td>
<td>137.38±5.20</td>
<td>260.67±22.99</td>
<td>200.40±5.92</td>
</tr>
<tr>
<td>HDL-C (mg dL⁻¹)</td>
<td>54.60±4.25</td>
<td>40.80±1.11</td>
<td>42.20±0.93</td>
</tr>
<tr>
<td>LDL-C (mg dL⁻¹)</td>
<td>107.14±10.62</td>
<td>151.67±4.44</td>
<td>141.32±5.06</td>
</tr>
<tr>
<td>VLDL-C (mg dL⁻¹)</td>
<td>27.48±1.04</td>
<td>52.13±4.60</td>
<td>40.08±1.18</td>
</tr>
</tbody>
</table>

Table 2: Serum levels of some antioxidants and trace elements in the different studied groups (Means ± SE)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>Diabetic</th>
<th>Diabetic + LA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOD (µ mL⁻¹)</td>
<td>13.09±0.83</td>
<td>5.68±0.19</td>
<td>13.48±0.70</td>
</tr>
<tr>
<td>GSH (pmol)</td>
<td>27.93±1.20</td>
<td>18.93±0.77</td>
<td>26.20±1.14</td>
</tr>
<tr>
<td>Vit. C (µg mL⁻¹)</td>
<td>4.90±0.46</td>
<td>2.50±0.17</td>
<td>3.54±0.29</td>
</tr>
<tr>
<td>Zn (µg L⁻¹)</td>
<td>143.73±2.95</td>
<td>116.13±3.72</td>
<td>144.20±6.40</td>
</tr>
<tr>
<td>Se (µg L⁻¹)</td>
<td>16.40±1.05</td>
<td>13.60±1.25</td>
<td>16.76±0.86</td>
</tr>
<tr>
<td>Cu (µg L⁻¹)</td>
<td>2.37±0.12</td>
<td>3.61±0.16</td>
<td>3.24±0.13</td>
</tr>
<tr>
<td>Co (µg L⁻¹)</td>
<td>3.48±0.96</td>
<td>2.96±0.19</td>
<td>3.34±0.20</td>
</tr>
</tbody>
</table>

A: Significant and control; B: Significant and diabetic

Table 3: Correlations between different parameters in diabetic untreated and LA treated groups

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Group</th>
<th>r</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose and SOD</td>
<td>LA treated</td>
<td>0.80</td>
<td>0.001</td>
</tr>
<tr>
<td>Glucose and Se</td>
<td>LA treated</td>
<td>0.80</td>
<td>0.001</td>
</tr>
<tr>
<td>HOMA and SOD</td>
<td>diabetic untreated</td>
<td>-0.53</td>
<td>0.040</td>
</tr>
<tr>
<td>HOMA and SOD</td>
<td>LA treated</td>
<td>0.61</td>
<td>0.010</td>
</tr>
</tbody>
</table>

Administration of α-lipoic acid produced strong positive correlations between serum level of fasting glucose and both SOD and Se (r = 0.8). In addition, significant negative correlation was observed between HOMA index and serum level of SOD (r = -0.53) in diabetic group, which changed into positive correlation (r = 0.61) after administration of lipoic acid (Table 3).

### DISCUSSION

Under fasting conditions, glucose homeostasis is maintained by the balance between systemic glucose production and total-body glucose utilization. The increase in glucose production can be largely attributed to an elevation in the gluconeogenesis rate and appears as the main cause of fasting hyperglycemia, which is particularly evident in a certain percentage of diabetic patients (Khamaisi et al., 1999).

The present results showed a state of insulin resistance in diabetic patients, as demonstrated by significant elevation of serum glucose, insulin levels and higher value of HOMA index as compared with control. Administration of α-lipoic acid improved significantly this insulin resistance as observed by the reduction in insulin and HOMA values. These results agree with those of Jacob et al. (1995); Jacob et al. (1996) and Konrad et al. (1999).
Lipoic acid was found to enhance expression of the Insulin Receptor Substrate-1 (IRS-1) protein in muscle of obese Zucker rats (Saengsirisuwan et al., 2004). In addition, LA proposed to recruit GLUT4 in skeletal muscles from its storage site, so that glucose uptake is stimulated by the local increase in transporter (Shay et al., 2009). Unchanged serum glucose level in LA group may be due to insufficient time duration of the experiment.

Dyslipidemia, hallmarkd by low plasma HDL-C and high LDL-C and triacylglycerol levels, is common in patients with diabetes mellitus (Mahfouz et al., 2007). Insulin is an important hormone in regulating lipid metabolism in a variety of animal tissues; it can both decrease lipolysis and cause an increase in triglyceride synthesis of adipose tissue.

The present study revealed pronounced elevations in the serum levels of the lipid profile except HDL-C which showed significant reduction in diabetic group. Type 2 diabetes is usually associated with higher concentrations of TC and TG and lower concentrations of HDL-C. Insulin resistance is likely underlies these changes (Garvey et al., 2003; Rosenson, 2006).

In this study, the serum level of VLDL-C was much elevated in diabetic group in relation to control group. Krauss and Siri (2004) reported that the mechanisms responsible for hypertriglyceridaemia may be an increased hepatic secretion of VLDL and a delayed clearance of TG-rich lipoproteins, which might mainly be due to increased levels of substrates for TG production, free fatty acids and glucose. Triglyceride-enrichment lipoproteins lead to increased production of the small dense form of LDL cholesterol and to depletion of HDL cholesterol (Duell et al., 1991).

In this study, although oral administration of LA improved significantly the serum levels of TG and VLDL-C toward the control values, the levels of LDL-C and HDL-C showed no significant improvement. The mechanism by which ALA improves the dyslipidemia is still unclear. One of the actions which might attribute to this finding is by decreasing the non-esterified fatty acid levels. The mechanism of action is also believed to be through the controlling activities of enzymes that involves in lipid metabolism. ALA was reported to reduce HMG-CoA reductase activities as well as increases the lipoprotein lipase and Lecithin Cholesterol Acyl Transferase (LCAT) activities (Siti et al., 2007).

Free radical production can be enhanced during hyperinsulinemia and hyperglycemia by mechanisms such as autoxidation of glucose, enhanced glycation and altered polyol pathway (Mahfouz et al., 2009).

In the present study, there was a significant decrease in serum levels of SOD, GSH and vitamin C in diabetic group, compared to control. However, oral administration of LA improved significantly the antioxidant defense mechanism in these patients.

Lipoic acid is a unique antioxidant because it has beneficial effects on fuel metabolism and also an essential cofactor of mitochondrial respiratory enzymes, including the pyruvate dehydrogenase complex (Siti et al., 2008). It is said that LA offer advantages over other antioxidants as it increases the level of reduced glutathione (Osfor et al., 2010) and can also regenerate other antioxidants such as vitamin C and E (Cakatay et al., 2005).

The reports about the SOD activity in diabetes mellitus are controversial, with some authors reporting no change in SOD activity (Ramazan et al., 2000 and Kesavulu et al., 2000) while others reported increased activity (Maritim et al., 2003; Sailaja et al., 2003). There are also reports of decreased SOD activity in diabetic patients. A decreased level of GSH indicates decreased scavenging capacity of glutathione-dependent anti-oxidant defensive system against elevated lipid peroxidation processes in these patients (Soliman, 2008).

The improvement in SOD level in our diabetic patients may be due to the improvement in Zn level since extracellular SOD is Cu-Zn dependent (Zelko et al., 2002), since zinc ions stabilize the apoprotein whereas Cu is a prosthetic group of the active site of SOD.

The increase in lipid peroxidation and the decline in antioxidant defense may appear early in type 2 DM patients, before the development of secondary complications and might play an important role in the initiation and progression of diabetic complications (Soliman, 2008). LA converted the negative correlation between SOD and both HOMA index and fasting glucose in diabetic patients into a positive correlation in the diabetic treated group. This means that LA appears to improve the antioxidant capacity in face of the oxidative stress induced by insulin resistance in type 2 DM. From all of the above, LA appears to have a potent therapeutic role in addition to its role in management of diabetic neuropathy in protection of diabetic complications due to oxidative stress.

Zinc and selenium may have utility in the treatment of the complex disorders in type 2 diabetes and may help in the control of blood glucose and lipids, thus preventing or delaying serious clinical events (Kamal et al., 2009).

Results of the present work revealed significant reduction in serum level of Zn in diabetic group compared to non-diabetics as reported earlier (Zheng et al., 2008; Kazi et al., 2008;
Viktorinová et al., 2009; Hussain et al., 2009). However, comparable serum levels of zinc in the type 2 diabetic patients and normal subjects have been reported elsewhere (Walter et al., 1991). Nevertheless most studies have found an increased urinary zinc loss in these patients (Hagglof et al., 1983; Faure et al., 1993).

In this study, treatment with LA returned the serum levels of Zn and Se to the normal control values. Zinc results are in line with those reported by Kayali et al. (2007), while for Se, as a matter of fact, there are no studies in the literature about the effect of LA on serum Se. The normalization of serum levels of Zn and Se may be due to the improvement in the insulin sensitivity as indicated by the lowered value of HOMA. Interestingly, the normalization of the Zn and Se was accompanied by a decrease in lipid abnormalities which could reflect the role of these trace elements as biological antioxidants.

The redox chemistry of Cu makes this both a powerful enzyme catalyst and a dangerous reactant that generates hydroxyl radical. Abnormal copper metabolism can lead to several chronic pathogenesis, such as diabetes or diabetic complications (Hussain et al., 2009).

The present study revealed significant elevation in the serum level of Cu in diabetic group. Other studies found that in diabetic patients, circulating copper concentrations were not different (Bo et al., 2008; Hussain et al., 2009) or were greater (Zargar et al., 1998 and Abu-seif and Youssef, 2004). Treatment with LA did not reduce the elevated serum level. On the contrary, Osfor et al. (2010) indicated that injecting Cu-intoxicated rats with α-LA significantly reduced serum copper.

The present study did not find correlation between copper and any of the studied parameters. Consequently, the increased copper levels found in diabetics in our study may merit further investigation of the relationship between copper and type 2 DM.

Although diabetic untreated group showed reduction in the serum level of Co which improved and returned to the control value in lipoic acid treated group, but these alterations were not statistically significant. Serum Cu and Co concentrations are perhaps not the best index of total body Cu and Co.

**CONCLUSION**

It is concluded that oral administration of LA to type 2 DM alleviated the glycemic status and oxidative stress in addition to Zn and Se serum levels. Consequently, LA may delay the diabetic complications.

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