Introduction

Oxidation of fatty acids constitutes an essential metabolic process boosting resistance capabilities of both humans and other rodents. Oxidation pathways of fatty acids provide triggered by aerobic reactions of the TCA cycle within muscle tissues which produces a high rate of ATP necessitated for muscle contractions during long-term exercises. Therefore, an increase in fatty acid oxidation during endurance exercise reduces the consumption of carbohydrates as an energy source, suppresses lactate production, and thereby, improves endurance capacity. In this regard, many studies have been conducted in order to improve exercise performance through nutritional supplementation which increases the fatty acid oxidation. Most athletes use nutritional manipulation to improve their performance. Among all substances which are usually used, L-carnitine is consumed by athletes as an energy producing aid due to its effect in transferring long-chain fatty acids across the mitochondrial membrane.

L-carnitine supplementation not only increases the oxidation of fatty acids during exercise but also helps to maintain glycogen stores. In mammals carnitine can be generated from the essential leucine and methionine amino acids of foods. The major source of carnitine is red meat and dairy products. But today commercial products of carnitine are also available.

In a study by Kashef et al, they examined the effect of 4 weeks of exercise training along with L-carnitine supplements on performance capacity and blood lactate levels. In their study, the participants were placed in three groups: a control group, a L-carnitine group, and a placebo group. The results showed that the L-carnitine group had a lower lactate concentration and a higher VO2max than the placebo group. The L-carnitine group also showed a trend towards improved performance capacity, indicating that L-carnitine supplementation may be effective in improving endurance performance.
groups: supplements, supplements and training, and training groups. The training program included 45 minutes of periodic exercise. The results showed that after 4 weeks of L-carnitine consumption, no change occurred in blood lactate level after an exhaustive exercise (Bruce test) in any of the study groups. However, aerobic capacity and time to exhaustion significantly increased in the supplement and supplement-training groups. Nevertheless, in another study the consumption of L-carnitine supplement for 3 weeks did not result in any change in parameters like lactate, submaximal heart rate, glucose and maximal oxygen consumption after 20-minute cycling submaximal test created by Astrand protocol. In fact, the consumption of chronic L-carnitine did not improve the performance and the aforementioned factors. Despite these findings, the effect of acute consumption of L-carnitine on acid lactate, glucose and oxygen saturation followed by an aerobic exercise test (Bruce test) is not still clear. Therefore, our aim was to assess the role of acute L-carnitine administration on lactate, glucose, oxygen saturation and VO2max in active young men.

Methods
This was a semi-experimental double blind study. Ten young male students with mean values for age; 26.4 ± 0.96, height; 173.90 ± 9.45, weight; 71.80 ± 5.63 and body fat of 13.62 ± 2.64 volunteered to take part in this study. Each person took part at least in 3 exercise sessions in each week and every session lasted for 1-1.5 hours. The 10 participants consumed 200 mL of lemon juice solution (200 mL water with few lemon drops as a placebo) in the first test, and 3 g of L-carnitine (oral solution L-carnitine BSK, made in Iran) in 200 mL of water with a few drops of lemon juice (as L-carnitine supplement) in the second test 90 minutes before taking the tests. The 2 tests were taken by the same subjects at one-week interval. The exercise test used in this study was Bruce incremental test in which along with the gradual increase in speed, the slope, with initial 10%, also increased by 2% every 3 minutes and the participants continued exercising until they were exhausted and could not tolerate treadmill speed. At this point tests were stopped. Usually at this point the heart rate of participants was above 175 beat/min. Initial measurements were made 15 minutes before the Bruce test (after 15 minutes of sitting in the lab and 4 hours after the meal). Levels of blood sugar (glucose), heart rate and oxygen saturation were measured immediately after completion of the test and 3 minutes after that. Lactate values were measured four minutes after the end of the test. In summary, oxygen saturation, heart rate and blood glucose were measured three times (before, immediately after and 3 minutes after), however lactate levels were measured two times (before and 4 minutes after). Finally, we should mention that 2 exercise tests were performed in the given time (4 PM) and in the same environment in room temperature (23°C) with 50% relative humidity in exercise physiology laboratory salon of Shahid Rajaee Teacher Training University.

Results
Ten young college men took part in 2 exhausting exercise tests (Bruce test). These tests were separated with 1-week interval. In the first test, they received placebo and in the second test, subjects consumed 3 g of L-carnitine supplement 90 minutes before performing the test. The Shapiro-Wilk test indicated that data had a normal distribution (P > 0.05) and also the Levine test showed the homogeneity of variances (P > 0.05).

Statistical Analysis
Statistical analysis was performed using SPSS software version 23. Using repeated measures, data obtained from the 2 stages of the study (placebo and supplement) were compared with each other.

Instruments
Maximum oxygen consumption and aerobic capacity of the participants were measured using Bruce incremental test and the Sports Art treadmill model. To measure the body fat percent of the participants, In Body S10 (Bi-space CO. Ltd, Seoul, Korea) was used. Lactate was measured by taking blood from the fingertip using a lancet, a lactate scout analyzer, and test strips with code 37. To measure blood glucose, 01-mini ARKRAY Glucometer made in Japan was used. Heart rate and oxygen saturation were measured by plus-oximeter, Riester model made in Germany.

Figure 1. Changes in Glucose Levels in the L-Carnitine and Control Groups.
Statistical analysis of heart rate between the training sessions using 2-way repeated ANOVA did not show significant differences between the groups ($P = 0.962$). However, significant differences were found between different time periods in the control ($P < 0.001$) and supplement ($P < 0.001$) groups. Further analyses revealed that heart rate in the first and the second period ($P < 0.001$), the first and the third period ($P < 0.001$), and the second and the third period ($P < 0.001$) had significant differences in both groups (Figure 2). Statistical analysis of blood lactate levels between the training sessions using the 2-way ANOVA showed significant differences between the groups ($P = 0.001$). Significant differences were observed between the different time periods in both groups ($P < 0.001$). Statistical analysis indicated that blood lactate levels measured in the first and second sessions in both groups had significant differences ($P < 0.001$) (Figure 3).

Findings concerning oxygen saturation levels between the training sessions using 2-way ANOVA showed no significant difference between the 2 groups ($P = 0.691$). However, significant differences were observed between different time periods in the control ($P < 0.001$) and supplement ($P < 0.001$) groups. Further analyses revealed that oxygen saturation levels measured in the first and second period ($P < 0.001$), the first and third periods ($P < 0.001$), and the second and third periods ($P < 0.001$) had significant differences in both groups (Figure 4).

Statistical analysis of VO$_{2}\text{max}$ levels between the two sessions using paired t test showed significant difference between the groups ($P < 0.001$). The VO$_{2}\text{max}$ level was higher in the second session (Supplement) than the first session (control) (Figure 5).

**Discussion**

Since oxidation of fat needs more oxygen compared to carbohydrate, the cardiovascular system should receive more oxygen to muscles. In this regard, L-carnitine increases the consumption of oxygen and oxidation of lipids by stimulating pyruvate dehydrogenase complex and pyruvate entry into the beta-oxidation pathway.$^{11}$ The results of the current study represented that L-carnitine supplement group had a higher level of VO$_{2}\text{max}$ compared to
the placebo group and negative correlation was observed between blood lactate and VO$_{2}$max. Therefore, it seems that a decrease in blood lactate level can be the result of an increase in fatty acids oxidation, and finally can improve exercise performance. These findings are in accordance with the results found by Noorshahi and Ebrahimi in 2009.a But similar results were not observed in a research by Izadi et al, which can be due to long-term consumption of L-carnitine, excess excretion via urine and possible adjustments. Wächter et al reported that long-term L-carnitine supplementation had no impact on VO$_{2}$-max. Long-term consumption of L-carnitine supplement (4 g daily for 3 months) did not increase muscle carnitine, and thereby, no increase was observed in VO$_{2}$max. In this study, however, we could not measure the carnitine levels. Wächter et al indicated that consuming 2 g of L-carnitine for 24 weeks in the 2 activities with 50% and 80% VO$_{2}$max intensity on the bicycle ergometer can improve VO$_{2}$max. Intensities used in a study by Wächter et al were lower than those used in the present study, and this might have an effect on presenting the actual values of VO$_{2}$max, whereas the aerobic test used in this study was progressive and this could lead an individual to reach the real VO$_{2}$max. The longitudinally of Wächter and colleagues’ study and the probability of the participants’ compatibility with the training could be responsible for an increase in VO$_{2}$max compared to the effect of the supplement. Considering the effect of L-carnitine supplement in stability of the acetyl coenzyme to free coenzyme ratio and prevention from the accumulation of lactate, the results of the current study showed that after exercise, the supplement group had lower concentration of lactate in comparison with the placebo group that allowed L-carnitine group to reach higher amounts of VO$_{2}$max. Thus, the endurance capability may be improved. This is consistent with the results of some previous studies; however, Izadi et al did not observe significant differences in lactate concentrations. Presumably, the consumption of L-tartrate and heparin could have interfered with the effects of L-carnitine. Stuessi et al reported that L-carnitine administration has no effect on blood lactate levels. Since exercise reduces muscle carnitine, and thereby, increases the absorption of muscle carnitine, the participants’ gender, type and physical conditions of Stuessi and colleagues’ study could have caused failure to absorb sufficient carnitine in muscles and reach the required effective level. In their study, Wächter et al showed a reduction in lactate by 44% which can be due to the low intensity of exercises (50% and 80%), resulting in low accumulation of lactate concentration, whereas the intensity used in this study was maximum, thus, lactate accumulation was high. The longitudinally of Wächter and colleagues’ study and the probability of the participants’ compatibility with the training might have resulted in a decrease in lactate accumulation compared to the effect of the supplement. Of course, we have some limitations in performing this study.

The main role of carnitine is on the metabolism of lipids; however, evidences also support its possible participation on the carbohydrates biogenesis. Actually, there has been a significant association considering the muscle carnitine and the Krebs cycle. Oxidation process of lipids is stimulated after the administration of L-carnitine. Muscle carnitine concentration is definitely in accordance with glycogen stores within muscles. Due to its effect on storage and saving muscle glycogen for energy production process compared to beta oxidation, Carnitine acts as an anti-catabolic glycogen agent that effectively obviates the requirements for glycogen consumption. Panjwani et al in 2007 described no alternations on plasma glucose concentrations during exercise after L-carnitine administration. Other studies also support that L-carnitine has no effect on blood glucose levels. What distinguishes this study from the aforementioned studies is the level and time of L-carnitine consumption. The results of the present study also suggest that 3 g of L-carnitine supplementation has no effect on blood glucose levels. It is noteworthy that one of the limitations of this study is that the plasma level of L-carnitine was not measured before and after its supplementation in the sample. On the other hand, it is possible that L-carnitine supplementation leads to an increased oxidation of glucose similar to the animal models reported. In fact, this theory does not explain increased glucose consumption; rather, the theory of carnitine effect on increase glucose oxidation maintains that L-carnitine supplementation increases pyruvate conversion to acetyl-CoA and increases carbohydrate oxidation. In addition, it decreases pyruvate conversion to lactate and its accumulation by increasing the activity of pyruvate dehydrogenase. It is needed to say that in the present study, a decrease in glucose levels immediately after exercise test and recovery glucose levels after 3 minutes were similar between L-carnitine and placebo groups. So, probably acute L-carnitine supplementation cannot improve glucose recovery after maximal exercise test.

Increased level of VO$_{2}$max is a sign of improvement in athletes and non-athletes or patients’ cardiovascular fitness. In addition, decreased heart rate during rest or exercise is also another prominent physiological symptom which increases the level of aerobic fitness. Many studies have been conducted to assess the loading effect of carnitine on maximal oxygen consumption of athletes and non-athletes. Most studies have reported more or less improved VO$_{2}$max and optimal sport performance among elite athletes and recreational athletes after L-carnitine supplementation specifically after taking high doses in longer time periods. Daily consumption of 2 g of L-carnitine results in a considerable increase in VO$_{2}$max and the output along with reduced pulmonary ventilation, and CO$_{2}$ and lactate production. But Brass et al showed that L-carnitine has no effect on the value of VO$_{2}$max in patients with renal disease despite increased plasma concentrations of carnitine. Natali et al showed that oral carnitine supplementation resulted in a small reduction of heart rate by exercising with 50% intensity.
on VO\textsubscript{max}. This suggests an improvement in the functioning of the circulatory system under submaximal exercise.\textsuperscript{28} But some findings reported no heart rate changes due to L-carnitine supplementation.\textsuperscript{28} Our results indicated that acute consumption of L-carnitine supplement did not have an effect on the recovery of heart rate 3 minutes after exercise test. Another study revealed that 2-month consumption of omega-3 can improve recovery heart rate (1 minute after exercise).\textsuperscript{29} However, chronic effects of L-carnitine on heart rate recovery is unknown and more studies should be conducted in this field. Moreover, in the current report, L-carnitine treatment before one session of exercising showed no significant change in the amount of oxygen saturation. The reason may be the dose of L-carnitine, the fitness condition of the participants and the intensity of the activity. The current study showed that L-carnitine supplementation before exercise reduced blood lactate and increased VO\textsubscript{max} in young men and importantly the L-carnitine supplement did not affect the blood glucose and maximum heart rate after exhausting test. Major limitations of this study were that we could not control and match the food regimen and activity levels of subjects during the week of the exercise session and specially one day before the test.

**Conclusion**

The findings of our experiment revealed that L-carnitine supplementation can improve performance in exhausting test and the improvement is partly associated with a decrease in lactate production.

**Ethical Approval**

This study was approved by Sport Sciences Research Institute of Iran.

**Competing Interests**

Authors declare that they have no competing interests.

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**References**


