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The Role of L-Carnitine in Distance Athletes

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Abstract The purpose of this study was to perform a systematic review and summarize the current literature regarding L-carnitine and the potential role of sports especially in distance athletes. L-carnitine is a naturally occurring compound that plays an important role in mitochondrial β-oxidation. The main role of L-carnitine is to promote weight loss by increasing calorie expenditure. Also, L-carnitine plays an important role on recovery from strenuous exercise and may help to achieve quicker recovery and reduce muscle soreness. Finally, the results indicate that there is uncertainty in regards to how L-carnitine helps athletic performance. There are only three studies in the literature showing beneficial effects of L-carnitine on performance of athletes. On the contrary, three other studies have shown no effect of L-carnitine on performance.

Keywords L-carnitine, Distance athletes, Supplementation, Exercise, Performance

1. Introduction

Carnitine (L-3-hydroxytrimethylamminobutanoate) is an endogenous compound that can be synthesized in the liver and kidney from the essential amino acids lysine and methionine or ingested through diet [8, 10, 27, 57]. L-carnitine plays a critical role in energy production and in fat metabolism through its function as a transporter of long-chain fatty acids into mitochondria for β-oxidation [17]. In cells, it helps transport fatty acids into the mitochondria, where they can be burned for energy. Primary sources of dietary carnitine are red meat and dairy products. L-carnitine is stored primary in skeletal muscle (98%), but also in a much lower concentrations is found in plasma [6, 15].

L-carnitine often receives patients with regular hemodialysis, with metabolic disorders and in pregnancy [33, 42]. However, L-carnitine plays a crucial role in exercise and among athletes. A few studies demonstrated the effects of L-carnitine in endurance athletes. Endurance athletes use this supplementation to increase the oxidation of fat during exercise and spare muscle glycogen [25]. One of the main functions of performance enhancing drugs is to increase the amount of red blood cells. It is often times overlooked, be-cause of the obvious anabolic effects of performance enhancing drugs. By increasing the oxygen carrying capability of the blood, it helps give the body an additional boost especially in stressful situations.

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2. Different types of L-Carnitine

2.1. Acetyl-L-Carnitine

Acetyl-L-carnitine, or ALCAR, is L-carnitine to which an acetyl group (-COCH3) has been added, is thought to be the most bioavailable form of L-carnitine. Acetyl-L-Carnitine is an amino acid the body uses to turn fat into energy. It may also be used to treat neurological conditions such as Alzheimer's disease. Also, is a popular endurance supplement that plays a key role in energy production. There are many benefits of this supplementation for endurance athletes, but the most important are that improve exercise performance, improve recovery after following exercise, reduce muscle damage and soreness, increase ATP levels and improve antioxidant status.

2.2. Propionyl-L-Carnitine

Also, is formed principally during amino acid catabolism [44]. The main role of PLC is that helps the body to produce energy. Furthermore, PLC is known to decrease lipid peroxidation or the process wherein lipid membranes are attacked by free radicals, causing cellular damage [3, 34]. Also helps increase the production of nitric oxide, which promotes blood circulation and regulates blood pressure [2]. For endurance athletes, cellular damage could mean longer recovery times and be more prone to muscular injuries in training sessions. Also, is formed principally during amino acid catabolism.

2.3. L-Carnitine L-Tartrate

L-carnitine L-tartate is the one of the most common forms found in sports supplements, due to its rapid absorption rate [13, 49, 45]. This supplement is found to decrease muscle damage during recovery from resistance

exercises [23]. Several studies found that 3 weeks supplementation with L-carnitine L-tartate reduces muscle damage produced by an acute bout of high intensity resistance exercise [28, 50].

3. L-Carnitine Deficiency

L-carnitine deficiency is caused by a deficiency in the plasma membrane carnitine transporter with urinary carnitine wasting causing systemic carnitine depletion. Intracellular carnitine deficiency impairs the entry of long-chain fatty acids into the mitochondrial matrix [16]. Systemic primary carnitine deficiency is characterized by episodes of hypoketonic, hypoglykemia, hepatomegaly, elevated transaminases, and hyperammonemia in infants; skeletal myopathy, elevated creatine kinase (CK), and cardiomyopathy in childhood; or fatigability in adulthood [14]. The diagnosis is established by demonstration of low plasma free carnitine concentration (<5 μM, normal 25-50 μM), reduced fibroblast carnitine transport (<10% of controls), and molecular testing of the SLC22A5 gene on newborn screening [31].

In a Japanese study [29], primary systemic carnitine deficiency was estimated to occur in 1 per 40,000 births. Wilcken et al. [2003] reports that in Australia the incidence has been estimated to be between 1:37,000-1:100,000 newborns. The frequency of this condition in adults is not known. However, in the United Kingdom, a previous report identified 4 affected mothers in 62,004 infants screened, with a frequency of 1:15,500. No studies have estimated the incidence of primary carnitine deficiency in the United States and in Europe, however is estimated to occur in approximately 1 in 20,000-70,000 individuals based on newborn screening data from various states including Missouri, Texas, and California.

4. L-carnitine and Weight Loss

Three studies found dietary carnitine intake to be important, and evidence suggests it may promote weight loss by increasing calorie expenditure [24, 46, 47]. The study of Stephens et al. [47] found that dietary carnitine intake to be important supplementation with L-carnitine (of 2 x 1.36 g per day for 12 weeks) helps to prevent gains in body weight associated with increased energy intake. This maybe attributable, at least in part to the increased muscle carnitine concentrations (of up to 20%); increased energy expenditure rates (of 6%); and/or enhanced expression of genes involved in energy breakdown and storage [47].

A systematic review and meta-analysis of randomized control trials testing the effects of L-carnitine on weight loss [38]. In this meta-analysis were included nine studies and the participants supplemented with L-carnitine for at least one month. The results from meta-analysis suggested that supplementing with L-carnitine led to a 1.33 kg greater weight loss, on average, compared to a placebo. L-carnitine supplementation led to significant weight loss in diabetic and non-diabetic individuals, as well as obese and nor-mal-weight people. Additionally, the meta-analysis showed that the weight loss effects of L-carnitine are strongest in the beginning but decrease over time. However, the relevance of these findings is unclear because the included studies varied widely in their design. In summary, this me-ta-analysis of randomized controlled trials suggests that supplementing with L-carnitine for more than a month may promote modest weight loss.

5. L-carnitine and Recovery from Strenuous Exercise

Found only two studies in distance runners that referred on the effects of L-Carnitine in recovery after high intensity training (Table 1). In a study by Colombani et al. [11], demonstrated that an acute L-carnitine supplementation had no ergogenic effect and did not improve the recovery in endurance-trained athletes performing a long-distance run. Moreover, the study of Stuessi et al. [48] examined the effects of L-carnitine on recovery after exhaustive endurance exercise. Twelve subjects received either 2 g L-carnitine. Two hours after administration, the subjects performed a constant-load exercise test cycling at their individual anaerobic threshold to exhaustion. They found that 2 g of L-carnitine taken 2 h before a first of two constant-load exercise tests had no influence on the second tests performed 3 h after the first test. Also, one study used active healthy men. More especially, in a study by Parandak et al. [37] 21 active healthy young men were given either 2 g L-carnitine or a placebo daily for two weeks prior to an athletic test. Compared to the control group, those who took L-carnitine were found to have lower levels of certain markers that indicate muscle damage.

Moreover, some studies used in untrained subjects and examined the effects of L-carnitine in recovery after intensive exercise (Table 1). Initially, in a study by Giamberardino et al. [18] six untrained male followed a 7 weeks during which each subject: a) was given 3 g/d of L-carnitine for 3 weeks and, after a week's interval, 3 g/d of L-carnitine for 3 weeks; b) performed 2 step tests on the first day of the 3rd and 7th week inverting the order of the exercising limb. In a separate set of experiments carried out 8 months later, the possible effects of training on pain parameters and creatine kinase levels were also investigated in the same subjects. It is concluded that L-carnitine has a protective effect against pain and damage from eccentric effort. Two papers from the same lab [22, 45] were also used in untrained male and female. L-carnitine supplementation was given for 3 weeks (2 g/d). After 3 weeks of L-carnitine supplementation loading, each participant then performed an acute resistance exercise. They found that L-carnitine supplementation can reduce chemical damage and muscle

soreness after physical exercise.

On the contrary, there are some studies that referred in resistance trained subjects (Table 1). Two studies from the same lab [28, 50] investigated the effects of L-carnitine supplementation on recovery after resistance exercise. The subject was 10 resistance trained men consumed L-carnitine supplement (2 g L-carnitine/day) for 3 weeks before obtaining blood samples on six consecutive days. Blood was also sampled before and after a squat protocol (5 sets, 15–20 repetitions). The results demonstrate that L-carnitine supplementation is effective in assisting recovery from high-repetition squat exercise.

6. Effects of L-carnitine on Athletic Performance and Recommended Dosage

Some athletes take L-carnitine to improve performance. However, three studies find no consistent evidence that carnitine supplements can improve exercise or physical performance in healthy subjects at doses ranging from 2–6 grams/day administered for 1 to 28 days [4, 5, 7]. (Table 2)

There is a debate about the effects of L-carnitine on athletic performance in distance runners. Some studies found that this supplementation improve athletic performance. More specifically, Gorostiaga et al. [19] suggested that 2 g of L-carnitine during 28 days increased lipid use in muscle and decreased respiratory quotient during submaximal exercise. Also, in the study of Arenas et al. [1] sixteen well-trained male athletes received 2 g orally of L-carnitine for 28 days and after the endurance athletes started a 4 weeks endurance training program. They found improvement in VO_2max after L-carnitine administration. (Table 2)

On the other hand, some studies have seen not improve of performance in distance runners. The study of Marconi et al. [32] found 6% increase of VO_2max in endurance runners. They suggested that this improvement is probably affected by variables, other than L-carnitine loading, of a physiological (e.g. initial muscle glycogen stores) and/or psychological nature. Also, Colombani et al. [11] examined the effects of L-carnitine supplementation on physical performance. Seven male subjects were given supplements of 2 g L-carnitine 2 h before the start of a marathon run and again after 20 km of the run. They found that acute administration of L-carnitine did not improve the physical performance of the endurance athletes during the run and did not alter their recovery. In the study of Greig et al. [20] examined the effects of 2 g oral supplementation of with L-carnitine for 2 and 4 weeks. The results of treatment with L-carnitine demonstrated no significant changes in VO_2max or in maximum heart rate. Furthermore, in the study of Wachter et al. [51] 8 male adults were treated with 2x2 g of L-carnitine per day for 3 months. Exercise tests were performed using a bicycle ergometer for 10 min at 20%, 40%, and 60% of the individual maximal workload, respectively, until exhaustion. They found that supplementation of L-carnitine is not associated with a significant increase. Moreover Cooper et al. [12] used loading of the athletes with L-carnitine for 10 days before running a marathon. The time of marathon run reduced by 3.2%, after loading of L-carnitine, but this improvement was small and not significant.

Moreover, some studies used in untrained subjects and examined the effects of L-carnitine on athletic performance. DiSilvestro et al. [53] suggested that 2 g orally of L-carnitine for 4 weeks improve aerobic exercise performance in fit young adult women. In the study of Shannon et al. [54] 21 untrained male received 3 g orally of L-carnitine for 24 weeks. They found improvements in VO_2max. Also, in the study of Burrus et al. [55] suggested that 3 g orally of L-carnitine 3 h prior to exercise did not improve time to exhaustion at 85% of VO_2max. In the review of Stephens et al [56], suggested that feeding of 2-5 g/d L-carnitine for 1 week to 3 months prior to bout of exercise had no effect on exercise performance.

Table 1. Studies that examine the effects of L-carnitine in recovery after strenuous exercise

Study	Population	Daily L-carnitine dose	Treatment duration (weeks)	L-carnitine effects
Colombani et al. 1996	7 male athletes	4 g orally	Day of event	Did not improve the recovery
Stuessi et al. 2005	12 male athletes	2 g orally	Day of event	Did not improve the recovery
Paradank et al. 2014	21 male active	2 g orally	2	Lower levels of CK and LDH
Giamberardino et al. 1996	6 untrained male	3 g orally	3	Protective effect against pain and damage
Ho et al. 2010	9 male and 9 female untrained	2 g orally	3	Reduce chemical damage and muscle soreness
Spiering et al. 2007	8 untrained men	1-2 g orally	3	Reduce muscle soreness
Kraemer et al. 2003	10 resistance trained men	2 g orally	3	Quicker recovery
Volek et al. 2002	10 resistance trained men	2 g orally	3	Effective in assisting recovery

CK: creatine kinase, LDH: lactate dehydrogenase

Table 2. Studies that examine the effects of L-carnitine on performance

Study	Population	Daily L-carnitine dose	Treatment duration (weeks)	Endpoints	L-carnitine effects
Marconi et al. 1985	6 competitive walkers	4 g orally	2	VO_2max, lactate, RQ	Increase in VO_2max, no change in RQ at fixed workload
Colombani et al. 1996	7 male athletes	4 g orally	Day of event	Marathon time and postrace lactate	No effects of L-carnitine
Arenas et al. 1994	16 male athletes	2 g orally	4	VO_2max	Improvement VO_2max
Gorostiaga et al. 1989	9 male and 1 female	2 g orally	4	RQ, VO_2, heart rate, lactate, plasma glucose at fixed workload	Decrease in RQ, no others significant changes
Wachter et al. 2002	8 trained male	4 g orally	12	VO_2max	No effects of L-carnitine
Cooper et al. 1986	10 male marathon runners	4 g orally	10 days	Marathon time	Reduce by 3.2%

VO_2max = maximal oxygen consumption during exercise; RQ = respiratory quotient (VCO2/O2).

7. Bioavailability of L-carnitine in Athletes

The bioavailability of L-carnitine from food can vary depending on dietary composition. Bioavailability of L-carnitine from oral supplements ranges from 14-18% of the total dose, 15.1 ± 5.3% for the tablet and 14.8 ± 5.1% for the chewable tablet [15, 39]. After oral doses of 1–6 g, the absolute bioavailability is 5–18%. Less is known re-garding the metabolism of the acetylated form of L-carnitine, acetyl-L-carnitine; however, bioavailability of acetyl-L-carnitine is thought to be higher than L-carnitine. In the studies of Sahajwalla et al. [41] and Segre et al. [43] reported an absolute bioavailability of 18% after a single oral dose of 100 mg/kg as L-carnitine solution. Also, Harper, Elwin and Cederblad [21] reported a value of 16% (1.98g as a single oral dose of 6 x 330mg tablets with 200mL of water). Finally, Rizza et al. [40] reported absolute bioavailability values of 16 ± 3% and 14 ± 2% for oral doses of 20 mg/kg (approx. 2 g) and 100 mg/kg (approx. 6 g), respectively.

8. Conclusions

L-carnitine is unique in its essential role in energy metabolism, transporting fatty acids across the mitochondrial membrane for subsequent breakdown and energy generation [23].

The main limitation of the present systematic review is the small number of included studies that used distance athletes. Although, the vast majority of the studies recruited untrained or resistance trained athletes.

The main role of L-carnitine is to help populations with certain conditions achieve a higher level of exercise performance, particularly those with various dimensions of cardiovascular disease. These results indicate that there is uncertainty in regards to how L-carnitine helps athletic performance. Found six studies that examined the effects of L-carnitine on athletic performance. From these six studies, three studies in the literature showing beneficial effects of L-carnitine on performance of athletes [1, 19, 32]. On the contrary, three of studies have shown no effect of L-carnitine on performance [11, 12, 51].

However, it is clear that L-carnitine plays an important role on recovery from strenuous exercise [22, 45]. The majority of studies suggested a dose of 2-4 g/d of L-carnitine.

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