L- Carnitine

Athletic performance enhancement

By Heidi Fritz MA, ND

L-carnitine (LC), so called after caro, the Latin for "meat," is a conditionally essential, trimethylated amino acid derivative that is involved in mitochondrial fatty acid transport (L carnitine monograph 2005, Flanagan 2010). See Figure 1. LC concentrates in muscle tissue including skeletal muscle and the heart where it facilitates entry of long chain fatty acids to the mitochondria for utilization and energy production through beta oxidation (L carnitine monograph 2005, Stephens 2007). As such, LC has been studied for a wide range of conditions affecting muscle or mitochondrial function. This article focuses exclusively on LC supplementation for performance enhancement in athletes.

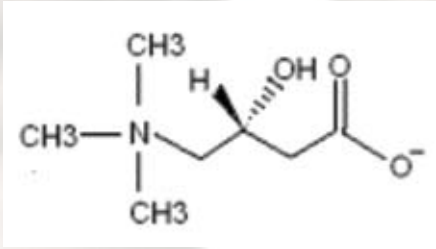

FIGURE 1. L-CARNITINE CHEMICAL STRUCTURE

PHYSIOLOGY

As the name suggests, LC in the diet is obtained primarily from meat. Dietary LC is absorbed with varying rates of efficiency through passive diffusion and active transport in the intestine; however, absorption becomes saturated at doses >2g. Elimination from the body occurs predominantly through the kidneys, with a half-life of 15 hours (L carnitine monograph 2005). LC can also be synthesized endogenously from the amino acids lysine and methionine (S-adenosylmethionine, SAMe) within the kidney, liver, brain, and testes; however, cardiac and skeletal muscle lack the synthetic enzyme, γ-butyrobetaine hydroxylase, and are thus dependent upon uptake from circulating carnitine (Flanagan 2010).

Deficiency states may be due to an inborn error of metabolism (primary deficiency) or, more commonly, associated with other disease states such as increased loss through dialysis in chronic renal failure, decreased synthesis in liver disease, or certain pharmacological therapies (secondary deficiency) (L carnitine monograph 2005). Over 150 clinical trials have investigated LC for these and other conditions; benefits have been reported for intermittent claudication and peripheral vascular disease, angina, congestive heart failure, neuropathy, chronic obstructive pulmonary disease, as well as others.

Heidi Fritz MA, ND
Research Fellow
Canadian College of Naturopathic Medicine
Bronte Naturopathic Clinic

1255 Sheppard Avenue East
Toronto, Ontario, Canada M2K 1E2
905 876 3047 ext 204
hfritz@ccnm.edu

MECHANISMS

LC impacts cellular energy metabolism by several mechanisms. The best known of these is LC's role in beta oxidation, however, other points of action have also been suggested:

- Beta oxidation – fatty acid transport
- Regulation of Acyl CoA : CoA balance – indirect facilitation of other reactions
- Vasodilation and increased oxygen delivery to muscle

ROLE IN MITOCHONDRIAL FATTY ACID TRANSPORT

To enter the β-oxidation pathway, long chain fatty acids within the cytosol (acyl-CoA) must combine with carnitine to form acylcarnitine and be transported across the otherwise impermeable inner mitochondrial membrane. Carnitine palmitoyltransferase 1 (CPT1) in the outer mitochondrial membrane catalyses this reversible reaction. Cytosolic acylcarnitine is then transported into the mitochondria in an exchange reaction with intra-mitochondrial free carnitine by the enzyme carnitine acylcarnitine translocase (CACT), located within the mitochondrial inner membrane. Once inside the mitochondrial matrix, acylcarnitine is transformed back to free carnitine and long-chain acyl-CoA by carnitine palmitoyltransferase 2 (CPT2). Translocation of acyl-CoA is the rate limiting step in fatty acid oxidation; after this, long-chain acyl-CoA can be oxidized and transformed for energy by the β-oxidation pathway (Stephens 2007) (Figure 2).

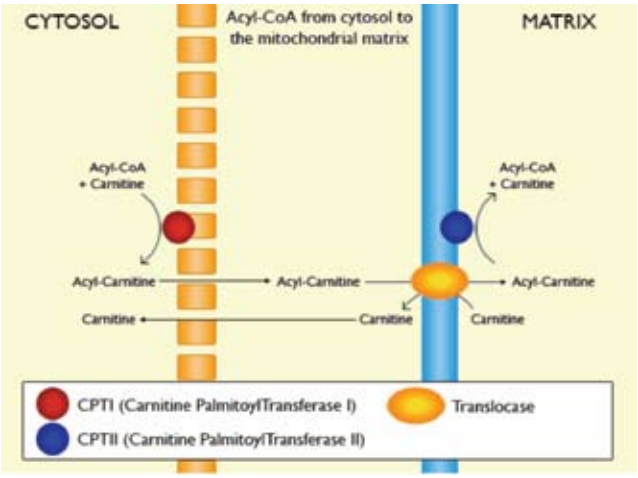

FIGURE 2. FATTY ACID TRANSPORT ACROSS THE MITOCHONDRIAL MEMBRANE

As well as facilitating fatty acid transport, LC regulates the ratio of acyl-CoA to CoA in the mitochondria (Stephens 2007). Inside the mitochonrdria, LC accepts acyl groups (fatty acid chains) from the CoA group, freeing up CoA for participation in other energy-releasing reactions, such as those involving glucose oxidation, for instance the pyruvate dehydrogenase (PDH) reaction (Higdon 2002). Thus L-carnitine also indirectly facilitates glucose utilization. More recently, LC has been proposed to have vasodilatory effects within the capillaries, potentially increasing oxygen delivery to muscle cells and "reducing local muscular hypoxia normally observed during high-intensity exercise [as well as] a cascade of events leading to free radical formation and chemical-induced tissue disruption and damage" (Kraemer 2003).

METHODS

Pubmed was searched from inception to September 2010 for controlled human trials investigating carnitine supplementation for effects on performance enhancement using the terms: "L-carnitine and (exercise or performance enhancement or ergogenic aid) not deficiency," limited to clinical trials, reviews, meta analyses, and yielding 199 studies, of which 35 relevant to LC supplementation for performance enhancement. Bibliographies of selected reviews were also searched for additional references, yielding 9, for a total of 44 altogether. The aim of this article is to provide a comprehensive overview of evidence supporting use of LC in athletes and kinds of outcomes obtained; therefore, due to space limitations, studies showing no significant effects with respect to LC for performance enhancement are only numbered and not discussed in detail.

CLINICAL EVIDENCE

Human evidence regarding LC's benefit as an ergogenic aid is mixed, with a large number of studies showing no effects as well as showing positive outcomes. Of the 44 studies, 25 showed benefits with use of LC, while 19 showed no significant effects. Please see the end of the article for complete references for the studies showing no effects. Table 1 summarizes available evidence from the twenty-five studies identified supporting use of LC.

LC has been shown to:

- ↓exercise induced muscle damage & ↑ repair
- ↓ hypoxic stress response of resistance exercise
- ↓ delayed onset muscle soreness (DOMS)
- ↑ VO2max (the maximal volume of oxygen consumed during exercise; a measure of physical fitness)
- ↑ cellular energy production
- ↑ exercise induced effects of anabolic hormones
- ↑ exercise capacity

A handful of high quality studies merit closer examination. These studies examined the effects of L-carnitine using near infrared spectroscopy (NIRS), magnetic resonance imaging (MRI), and radiolabelled 1-[(13)C] palmitic acid technology to assess muscle damage and oxygen utilization.

Table 1. Evidence Supporting L-Carnitine for Performance Enhancement in Athletes

Design	Outcomes	Reference
N=18 healthy, "normally active" adults LCLT (2g/d LC) x24d	• Significant attenuation of biomarkers of purine metabolism • ↓muscle tissue disruption (myoglobin, creatine kinase) • ↓muscle soreness, ($p<0.05$) for all these outcomes	Ho 2010
N=14 male cyclists Sports drink alone versus drink plus caffeine, carnitine, taurine, and B vitamin combination versus drink plus placebo. Dose not available	• Total work in kilojoules (KJ) was significantly greater in the group receving the drink plus combination ($p<0.05$) but not with the drink alond compared to placebo • Combination attenuated pre-to-post MVC declines • Combination resulted in lower ratings of perceived exertion throughout study ($p<0.001$)	Ganio 2010 [Abstr]
N=9 resistance trained men LCLT 2g/d x 23d	• Near infrared spectroscopy (NIRS) showed ↓muscle oxygenation after exercise and upper arm occlusion, suggesting ↑O2 consumption • ↓ plasma malondealdehyde, marker of membrane damage	Spiering 2008
Uncontrolled trial N=16 elite badminton players LC 2g single dose	• Significant ↑ in exercise maximum heart rate in men ($p<0.05$) • Respiratory exchange ratio was significantly improved at the anaerobic threshold ($p<0.05$) • Other parameters were unchanged	Eroglu 2008 [Abstr]
N=8 healthy men LCLT 0,1,or 2g/d x3wk	• Both 1 and 2g doses ↓ postexercise serum hypoxanthine, xanthine oxidase, serum myoglobin (markers of muscle damage) • ↓ perceived muscle soreness (DOMS)	Spiering 2007
N=10 resistance trained men LCLT 2g/d x3wk	• Muscle biopsy showed ↑ concentration of androgen receptors after exercise compared to placebo ($p<0.05$) • May promote muscle tissue recovery	Kraemer 2006
N=12 healthy active subjects LCLT- chronic or acute dose	• Chronic use significantly ↑ total carbohydrate oxidation in men compared to placebo ($p=0.02$) • No effects on fat oxidation or blood responses	Abramowicz 2005
N=19 healthy women LC as LCLT + choline x 3wk	• ↑fat mobilization measured by serum ß-hydroxybutyric acid. • ↑incomplete oxidation of fatty acids and disposal as acylcarnitines • Effects on performance not directly assessed	Hongu 2003
N=10 resistance trained men LCLT 2g/d x3wk	• MRI of thigh muscle showed ↓ exercise induced muscle damage compared to placebo • Significantly increased IGFBP-3 ($p<0.05$) before and after exercise, compared to placebo	Kraemer 2003
N=10 resistance trained men LCLT 2g/d x3wk	• MRI of thigh muscle showed muscle disruption of 41-45% that of the placebo group following exercise • Exercise induced ↑ in markers of muscle damage were attenuated by LCLT treatment ($p<0.05$) • Increases in plasma malondialdehyde (markter of membrane damage) normalized faster with LCLT	Volek 2002
Uncontrolled trial N=10 healthy subjects LC 1g/d x 10d	• 1-[(13)C] palmitic acid oxidation measured pre and post supplementation in resting individuals • Significant ↑ in (13)CO2 exhalation, indicating ↑long chain fatty acid oxidation ($p<0.01$)	Muller 2002
N=5 rugby athletes LC compared to water, caffeine, or LC+caffeine	• LC significantly ↑ endurance time compared with water control, and this was further ↑ in combination with caffeine. • LC alone had a greater effect on endurance than caffeine alone • Both agents offset exercise induced increases in total cholesterol, triglyceride, and free fatty acids in blood	Cha 2001 [Abstr]

N=6 untrained subjects LC 3g/d x 3wk	• Significant ↓ muscle pain, tenderness and CK release following 20 min eccentric exercise of the quadriceps, compared to placebo	Giamberardino 1996
N=16 long distance runners LC 2g/d x 4wk	• LC significantly ↑ activity of the PDH complex by increasing transformation of acetyl-CoA into acetylcarnitine • Indicates ↑cellular energy production	Arenas 1994
N=47 healthy subjects given a 10% glucose infusion, with or without 6g LC, two doses 1 wk apart	• LC reduced the resultant increase in plasma glucose through an insulin independent mechanism, suggesting increased glucose usage	Angelini 1993
N=14 long distance runners LC 2g 2x/d x 4wk	• Significantly ↑ free and total LC in muscle of the treated athletes; ↓ in the control group • ↑ respiratory chain enzyme activity in muscle	Huertas 1992
N=24 long distance runners and sprinters LC 2g/d x 6mo	• Long distance runners: LC offset a post exercise ↓ in plasma free LC levels • Sprinters: LC offset the post exercise ↓ in free and total LC in muscle tissue	Arenas 1991
N=7 healthy men LC 3g/d x 7d	• LC significantly ↓ the respiratory quotient compared to placebo under conditions of normal oxygenation ($p<0.01$), and • Under conditions of acute hypoxia at VO2 max near the anaerobic threshold	Wyss 1990
N=10 moderately trained men LC 2g single dose	• Significant post exercise ↓ plasma lactate and pyruvate, ↑ acylcarnitine • LC stimulated PDH activity, diverting pyruvate from lactate toward formation of acylcarnitine	Siliprandi 1990
N=10 moderately trained men LC 2g single dose	• LC significantly ↑ maximal oxygen uptake (VO2max) and power output at the maximal exercise intensity • ↓ CO2 production, pulmonary ventilation and plasma lactate, suggesting increased aerobic processes	Vecchiet 1990
N=110 elite child athletes LC 1g/d x 3wk or as a single dose	• Improvements in free fatty acids, triglycerides, lactic acid post exercise, evoked muscular potential, plasma carnitine • Similar results reported by Dagan 1987 [Abstr]	Dragan 1989 [Abstr]
N=10 endurance trained subjects LC 2g/d x 28d	• LC significantly ↓ the respiratory quotient during submaximal exercise • Trend toward ↑ O2 uptake, heart rate, blood glycerol, and resting plasma free fatty acids, suggesting ↑ lipid utilization	Gorostiaga 1989
N=14 elite cyclists Protein supplement with or without LC 2g/d x 10d	• LC significantly improved strength index, lean body mass, fat mass, total work per kilogram compared to the placebo group • Better performance in event setting, compared to placebo group	Dragan 1988 [Abstr]
N=6 long distance walkers LC 4g/d x 2wk	• Serum LC ↑ at rest and after exercise • VO2max ↑ 6% from 54.5 to 57.8 ml O2/kg-min ($p<0.02$)	Marconi 1985
*All studies are RCTs unless otherwise specified. Majority are of placebo controlled cross over design.		
Key: CK creatinine kinase; IGFBP-3 insulin like growth factor binding protein 3; LCLT L-carnitine L-tartarate; PDH pyruvate dehydrogenase		

Spiering (2008) used NIRS to examine the effect of LCLT (L-carnitine, L-tartarate combination) on muscle tissue oxygenation during and after multiple sets of squats (resistance exercise) as well as forearm oxygenation during and after brachial artery occulsion. NIRS measures the percentage of hemoglobin saturation in tissue. LC treatment led to significantly lower tissue hemoglobin oxygenation during artery occlusion compared to placebo, suggesting that LC increased tissue O2 consumption. During resistance exercise, there were no significant differences in oxygenation; however during the recovery period there was a brief period during which tissue hemoglobin oxygenation was also significantly lower with LC treatment (p-values not reported). These finding suggest that LC increases muscle oxygen consumption under conditions of hypoxia and during recovery from exercise.

Muller (2002) used 13-C radiolabelled palmitic acid to assess the effect of LC on cellular oxygen utilization. Ten healthy subjects underwent baseline testing with a single dose of radiolabelled palmitic acid, followed by LC treatment 3g/d for 10 days followed by a retesting

with ingestion of radiolabelled palmitic acid, 1g. As part of the radiolabelled 13-C test, breath samples were collected for 15 minutes for the following 15 hours to assess exhalation of 13-C as CO2. On the day of testing, all subjects were fed standardized meals. LC resulted in increased 13CO2 production in 9 of 10 subjects. LC increased 13-C exhalation from an average of 5.12% to 7% ($p<0.01$). This suggests that LC supplementation can increase fatty acid oxidation in healthy individuals.

Kraemer (2003) evaluated muscle damage and disruption using thigh MRI. Ten resistance trained men performed five sets of 15-20 squats with a load that was pre-designed to induce detectable muscle disruption but not severe damage on MRI. LC as LCLT was administered at 3g/d for three weeks prior to testing. MRI was conducted before the exercise test and at 1 and 4 days post-exercise. Blood hormone levels were also monitored. MRI assessment of exercise induced muscle disruption damage at 1 days and 4 days post exercise were 23 and 16% for LCLT and 39 and 29% for placebo, respectively. This was attributed to "enhanced the oxygen delivery to exercising muscles via a vasodilatory effect on the capillary, resulting in a reduced local muscular hypoxia" (Kraemer 2003). There were also some effects on the IGF (insulin like growth factor) system.

Volek (2002), part of the same research team as Kraemer above, used a similar methodology: 2g LC per day as LCLT for three weeks given to 10 resistance trained men who were assessed while performing squats with MRI and bloodwork. Serum markers of muscle damage and breakdown following exercise (hypoxanthine, xanthine oxidase, and serum uric acid, myoglobin, fatty acid-binding protein, and creatine kinase) were significantly ($p<0.05$) attenuated by LCLT. DOMS ratings were significantly lower in the LC group compare to placebo ($p<0.05$). The percentage of muscle tissue disruption in the LCLT group as assessed by MRI cross-sectional scans of the midthigh at 1 and 4 days post exercise was 41–45% less than that of the placebo group, representing significantly less muscle damage in the treatment group ($p<0.05$). Clinically, less muscle damage translates into a quicker recovery from exercise and a higher training capacity, for instance, increased frequency of work outs. It should be noted that three of these studies as well as several listed in Table 1 used LC in combination with L-tartarate, and it is possible that this substance also contributed to the overall results of the studies.

SAFETY

Although L-carnitine has been a a prescription substance in Canada for many years, it has recently undergone review by Health Canada and is in the process of becoming regulated as a non-prescription substance when used for conditions other than primary or secondary LC deficiencies (Health Canada 2009). LC possesses a high safety profile. Hathcock (2006) conducted a risk assessment review of LC and found that "evidence of safety is strong at intakes up to 2000 mg/d L-carnitine equivalents for chronic supplementation, and this level is identified as the OSL [observed safe level]."

LC is depleted by use of certain medications, including cyclosporin A, valproic acid, cisplain/ adriamycin (induced cardiac toxicity), however there is little evidence of deleterious interactions between LC and these drugs. There have been reports that LC may decrease side effects of these drugs, such as in valproic acid associated hepatotoxicity (Flanagan 2010).

CONCLUSION

L-carnitine is a well studied, natural, and safe way to improve performance in athletes. At doses of 2g/d it has been shown to increase cellular energy production, decrease muscle damage by close to 50%, decrease DOMS, increase muscle repair, and ultimately improve exercise performance. Although the totality of the evidence shows mixed outcomes, there is a large number of studies including a handful of very high quality studies showing benefit on these outcomes, very relevant to athletic performance. These findings may warrant consideration for use by athletes and practitioners seeking safe and natural strategies for performance enhancement.

References for Studies Showing No Effects

Barnett C, Costill DL, Vukovich MD, Cole KJ, Goodpaster BH, Trappe SW, Fink WJ. Effect of L-carnitine supplementation on muscle and blood carnitine content and lactate accumulation during high-intensity sprint cycling. Int J Sport Nutr. 1994 Sep;4(3):280-8.

Bloomer RJ, Smith WA, Fisher-Wellman KH. Oxidative stress in response to forearm ischemia-reperfusion with and without carnitine administration. Int J Vitam Nutr Res. 2010 Jan;80(1):12-23.

Bloomer RJ, Smith WA. Oxidative stress in response to aerobic and anaerobic power testing: influence of exercise training and carnitine supplementation. Res Sports Med. 2009 Jan-Mar;17(1):1-16.

Brass EP, Hoppel CL, Hiatt WR. Effect of intravenous L-carnitine on carnitine homeostasis and fuel metabolism during exercise in humans. Clin Pharmacol Ther. 1994 Jun;55(6):681-92.

Broad EM, Maughan RJ, Galloway SD. Carbohydrate, protein, and fat metabolism during exercise after oral carnitine supplementation in humans. Int J Sport Nutr Exerc Metab. 2008 Dec;18(6):567-84.

Broad EM, Maughan RJ, Galloway SD. Effects of four weeks L-carnitine L-tartrate ingestion on substrate utilization during prolonged exercise. Int J Sport Nutr Exerc Metab. 2005 Dec;15(6):665-79.

Colombani P, Wenk C, Kunz I, Krähenbühl S, Kuhnt M, Arnold M, Frey-Rindova P, Frey W, Langhans W. Effects of L-carnitine supplementation on physical performance and energy metabolism of endurance-trained athletes: a double-blind crossover field study. Eur J Appl Physiol Occup Physiol. 1996;73(5):434-9.

Decombaz J, Deriaz O, Acheson K, Gmuender B, Jequier E. Effect of L-carnitine on submaximal exercise metabolism after depletion of muscle glycogen. Med Sci Sports Exerc. 1993 Jun;25(6):733-40.

Greig C, Finch KM, Jones DA, Cooper M, Sargeant AJ, Forte CA. The effect of oral supplementation with L-carnitine on maximum and submaximum exercise capacity. Eur J Appl Physiol Occup Physiol. 1987;56(4):457-60.

Lee JK, Lee JS, Park H, Cha YS, Yoon CS, Kim CK. Effect of L-carnitine supplementation and aerobic training on FABPc content and beta-HAD activity in human skeletal muscle. Eur J Appl Physiol. 2007 Jan;99(2):193-9.

Nüesch R, Rossetto M, Martina B. Plasma and urine carnitine concentrations in well-trained athletes at rest and after exercise. Influence of L-carnitine intake. Drugs Exp Clin Res. 1999;25(4):167-71.

Oyono-Enguelle S, Freund H, Ott C, Gartner M, Heitz A, Marbach J, Maccari F, Frey A, Bigot H, Bach AC. Prolonged submaximal exercise and L-carnitine in humans. Eur J Appl Physiol Occup Physiol. 1988;58(1-2):53-61.

Smith WA, Fry AC, Tschume LC, Bloomer RJ. Effect of glycine propionyl-L-carnitine on aerobic and anaerobic exercise performance. Int J Sport Nutr Exerc Metab. 2008 Feb;18(1):19-36.

Soop M, Björkman O, Cederblad G, Hagenfeldt L, Wahren J. Influence of carnitine supplementation on muscle substrate and carnitine metabolism during exercise. J Appl Physiol. 1988 Jun;64(6):2394-9.

Stuessi C, Hofer P, Meier C, Boutellier U. L -Carnitine and the recovery from exhaustive endurance exercise: a randomised, double-blind, placebo-controlled trial. Eur J Appl Physiol. 2005 Dec;95(5-6):431-5.

Trappe SW, Costill DL, Goodpaster B, Vukovich MD, Fink WJ. The effects of L-carnitine supplementation on performance during interval swimming. Int J Sports Med. 1994 May;15(4):181-5.

Vukovich MD, Sharp RL, Kesl LD, Schaulis DL, King DS. Effects of a low-dose amino acid supplement on adaptations to cycling training in untrained individuals. Int J Sport Nutr. 1997 Dec;7(4):298-309.

Vukovich MD, Costill DL, Fink WJ. Carnitine supplementation: effect on muscle carnitine and glycogen content during exercise. Med Sci Sports Exerc. 1994 Sep;26(9):1122-9.

Wächter S, Vogt M, Kreis R, Boesch C, Bigler P, Hoppeler H, Krähenbühl S. Long-term administration of L-carnitine to humans: effect on skeletal muscle carnitine content and physical performance. Clin Chim Acta. 2002 Apr;318(1-2):51-61. 11880112.

References for Text

Abramowicz WN, Galloway SD. Effects of acute versus chronic L-carnitine L-tartrate supplementation on metabolic responses to steady state exercise in males and females. Int J Sport Nutr Exerc Metab 2005 Aug;15(4):386-400.

Angelini A, Imparato L, Landi C, Porfido FA, Ciarimboli M, Marro A. Variation in levels of glycaemia and insulin after infusion of glucose solutions with or without added L-carnitine. Drugs Exp Clin Res 1993;19(5):219-22.

Arenas J, Huertas R, Campos Y, Diaz AE, Villalon JM, Vilas E. Effects of L-carnitine on the pyruvate dehydrogenase complex and carnitine palmitoyl transferase activities in muscle of endurance athletes. FEBS Lett 1994 Mar 14;341(1):91-3.

Cha YS, Choi SK, Suh H, Lee SN, Cho D, Li K. Effects of carnitine coingested caffeine on carnitine metabolism and endurance capacity in athletes. J Nutr Sci Vitaminol (Tokyo) 2001 Dec;47(6):378-84.

Dragan GI, Wagner W, Ploesteanu E. Studies concerning the ergogenic value of protein supply and l-carnitine in elite junior cyclists. Physiologie 1988 Jul-Sep;25(3):129-32.
Dragan IG, Vasiliu A, Georgescu E, Eremia N. Studies concerning chronic and acute effects of L-carnitina in elite athletes. Physiologie 1989 Apr-Jun;26(2):111-29.

Dragan AM, Vasiliu D, Eremia NM, Georgescu E. Studies concerning some acute biological changes after endovenous administration of 1 g l-carnitine, in elite athletes. Physiologie 1987 Oct-Dec;24(4):231-4.

Eroglu H, Senel O, Guzel NA. Effects of acute L-carnitine intake on metabolic and blood lactate levels of elite badminton players. Neuro Endocrinol Lett 2008 Apr;29(2):261-6.

Flanagan JL, Simmons PA, Vehige J, Willcox MD, Garrett Q. Role of carnitine in disease. Nutr Metab (Lond) 2010 Apr 16;7:30.

Ganio MS, Klau JF, Lee EC, Yeargin SW, McDermott BP, Buyckx M, Maresh CM, Armstrong LE. Effect of various carbohydrate-electrolyte fluids on cycling performance and maximal voluntary contraction. Int J Sport Nutr Exerc Metab. 2010 Apr;20(2):104-14.

Giamberardino MA, Dragani L, Valente R, Di Lisa F, Saggini R, Vecchiet L. Effects of prolonged L-carnitine administration on delayed muscle pain and CK release after eccentric effort. Int J Sports Med 1996 Jul;17(5):320-4.

Gorostiaga EM, Maurer CA, Eclache JP. Decrease in respiratory quotient during exercise following L-carnitine supplementation. Int J Sports Med 1989 Jun;10(3):169-74.

Hathcock JN, Shao A. Risk assessment for carnitine. Regul Toxicol Pharmacol. 2006 Oct;46(1):23-8.

Health Canada. Food and Drug Regulations - Project 1656 - Schedule F. Updated 22 December 2009. http://www.hc-sc.gc.ca/dhp-mps/consultation/drug-medic/project_projet_1656-eng.php. Accessed 22 September 2010.

Higdon J. L-carnitine. Linus Pauling Institute. Oregon State University. Updated 2007 by V Drake. http://lpi.oregonstate.edu/infocenter/othernuts/carnitine/ Accessed 12 September 2010.

Ho JY, Kraemer WJ, Volek JS, Fragala MS, Thomas GA, Dunn-Lewis C, Coday M, Häkkinen K, Maresh CM. l-Carnitine l-tartrate supplementation favorably affects biochemical markers of recovery from physical exertion in middle-aged men and women. Metabolism. 2010 Aug;59(8):1190-9.

Hongu N, Sachan DS. Carnitine and choline supplementation with exercise alter carnitine profiles, biochemical markers of fat metabolism and serum leptin concentration in healthy women. J Nutr. 2003 Jan;133(1):84-9.

Kraemer WJ, Spiering BA, Volek JS, Ratamess NA, Sharman MJ, Rubin MR, French DN, Silvestre R, Hatfield DL, Van Heest JL, Vingren JL, Judelson DA, Deschenes MR, Maresh CM. Androgenic responses to resistance exercise: effects of feeding and L-carnitine. Med Sci Sports Exerc 2006 Jul;38(7):1288-96.

Kraemer WJ, Volek JS, French DN, Rubin MR, Sharman MJ, Gomez AL, Ratamess NA, Newton RU, Jemiolo B, Craig BW, Hekkinen K. The effects of L-carnitine L-tartrate supplementation on hormonal responses to resistance exercise and recovery. J Strength Cond Res 2003 Aug;17(3):455-62.

L-carnitine monograph. Alt Med Rev 2005; 10(1):42-50.

Marconi C, Sassi G, Carpinelli A, Cerretelli P. Effects of L-carnitine loading on the aerobic and anaerobic performance of endurance athletes. Eur J Appl Physiol Occup Physiol 1985;54(2):131-5.

Muller DM, Seim H, Kiess W, Loster H, Richter T. Effects of oral L-carnitine supplementation on in vivo long-chain fatty acid oxidation in healthy adults. Metabolism 2002 Nov;51(11):1389-91.

Siliprandi N, Di Lisa F, Pieralisi G, Ripari P, Maccari F, Menabo R, Giamberardino MA, Vecchiet L. Metabolic changes induced by maximal exercise in human subjects following L-carnitine administration. Biochim Biophys Acta 1990 Apr 23;1034(1):17-21.

Spiering BA, Kraemer WJ, Hatfield DL, Vingren JL, Fragala MS, Ho JY, Thomas GA, Hekkinen K, Volek JS. Effects of L-carnitine L-tartrate supplementation on muscle oxygenation responses to resistance exercise. J Strength Cond Res 2008 Jul;22(4):1130-5.

Spiering BA, Kraemer WJ, Vingren JL, Hatfield DL, Fragala MS, Ho JY, Maresh CM, Anderson JM, Volek JS. Responses of criterion variables to different supplemental doses of L-carnitine L-tartrate. J Strength Cond Res 2007 Feb;21(1):259-64.

Stephens FB, Constantin-Teodosiu D, Greenhaff PL. New insights concerning the role of carnitine in the regulation of fuel metabolism in skeletal muscle. J Physiol 2007 Jun 1;581(Pt 2):431-44.

Vecchiet L, Di Lisa F, Pieralisi G, Ripari P, Menabe R, Giamberardino MA, Siliprandi N Influence of L-carnitine administration on maximal physical exercise. Eur J Appl Physiol Occup Physiol 1990;61(5-6):486-90.

Volek JS, Kraemer WJ, Rubin MR, Gomez AL, Ratamess NA, Gaynor P. L-Carnitine L-tartrate supplementation favorably affects markers of recovery from exercise stress. Am J Physiol Endocrinol Metab 2002 Feb;282(2):E474-82.

Wyss V, Ganzit GP, Rienzi A. Effects of L-carnitine administration on VO2max and the aerobic-anaerobic threshold in normoxia and acute hypoxia. Eur J Appl Physiol Occup Physiol 1990;60(1):1-6