Eduvest – Journal of Universal Studies
Volume 4 Number 11, November, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

Effects of L-Carnitine on blood pressure, VO2 max, and endurance in athletes: Systematic Review

Annisa Lazuardi Larasati[1], Rani Sauriasari[2]*, Arry Yanuar[3]
[1,2,3] Fakultas Farmasi, Universitas Indonesia, Indonesia
Email: annisalazu@gmail.com, rani@farmasi.ui.ac.id, arry.yanuar@ui.ac.id

ABSTRACT

When playing sports, athletes are required to always maintain their health to provide maximum results in their performance. Supplements are products intended to complement nutritional needs, maintain, enhance and/or improve health functions and have nutritional value and/or physiological effects. L-Carnitine is a health supplement that is widely consumed by athletes. L-Carnitine has many effects on the body and the main effects are seen on blood pressure and VO2 max. The aim of this review is to look at the effects of L-Carnitine on blood pressure and VO2 max. It was found that L-Carnitine had more effect on a person's diastolic than systolic at doses of more than 2 grams/day. Meanwhile, the effect on VO2 max was seen in long-term use of 2 grams for 24 weeks and found a significant increase in VO2 max ($p<0.05$). L-Carnitine does influence blood pressure, VO2 max and is also correlated with endurance, but until now there is still a need for more research to show that the effects produced by L-Carnitine are significant both on blood pressure and VO2 max in athletes

KEYWORDS *L-Carnitine, blood pressure, VO2 Max, Athletes, Endurance.*

INTORDUCTION

Athletes are required to maintain health in order to provide good results in their performance. Most athletes use supplements as part of their nutritional needs. Health supplements are products intended to supplement nutritional needs, maintain, enhance and/or improve health functions, have nutritional value and/or physiological effects, contain one or more ingredients in the form of vitamins, minerals, amino acids and/or

How to cite: Larasati A,L et al (2024). Effects of L-Carnitine on blood pressure, VO2 max, and endurance in athletes: Systematic Review. *Journal Eduvest. 4* (6): 10489-10499
E-ISSN: 2775-3727
Published by: https://greenpublisher.id/

other non-plant ingredients. which can be combined with plants (Kementrian Kesehatan RI, 2019).

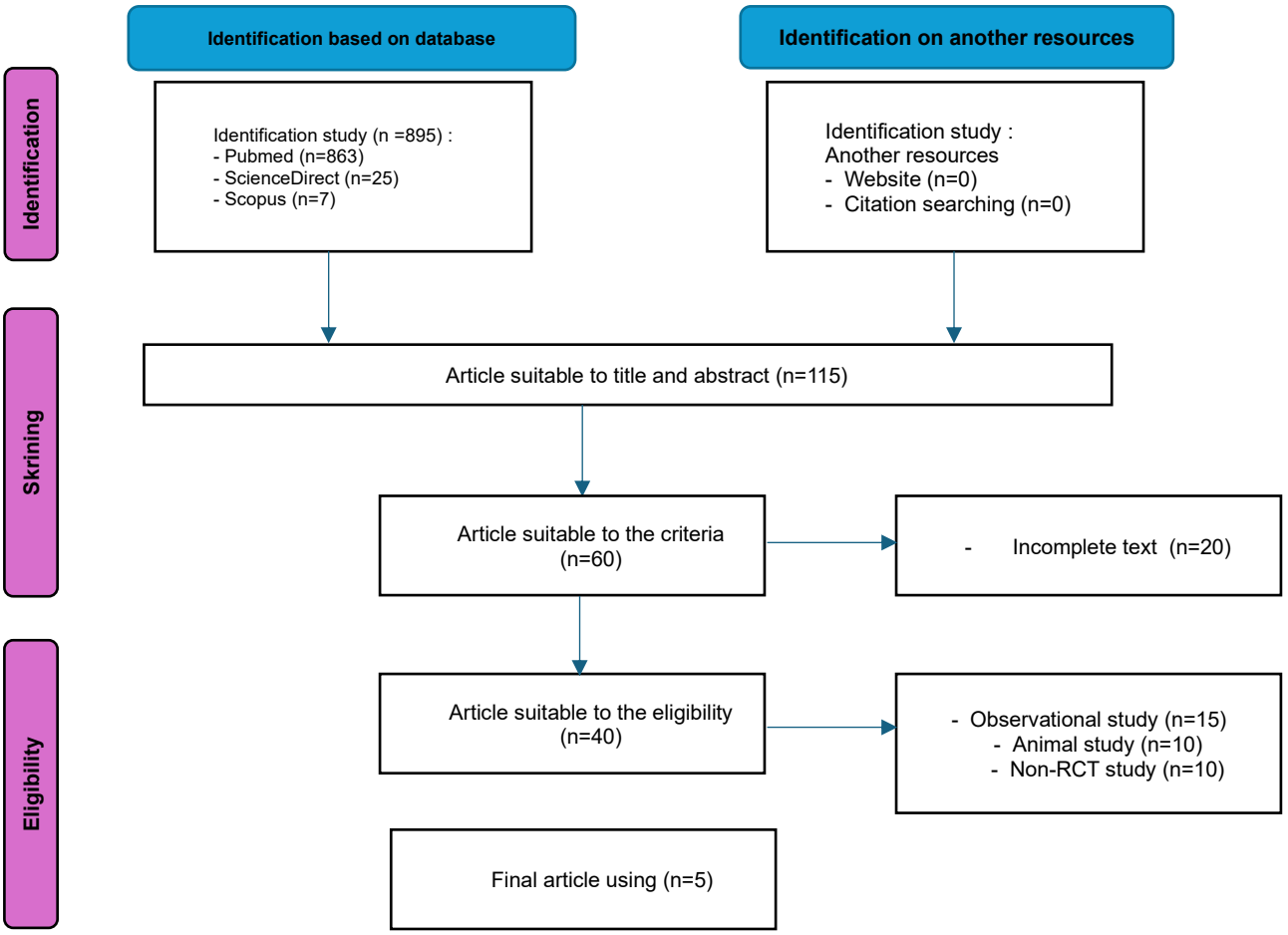
L-carnitine is a supplement that is often used by athletes as an aid in producing energy because of its effect in transferring long chain fatty acids that can cross the mitochondrial membrane (Bacurau et al., 2003). The use of L-carnitine as a supplement became popular when it was used by the Italian national football player in 1982 (Karlic & Lohninger, 2004). Carnitine in muscles can be increased in humans by means of intake, and carnitine has a dual role in burning metabolism and depends on the intensity of a person's training (Wall et al., 2011) . Basically, L-carnitine is a transporter of fatty acids into the mitochondrial matrix, allowing cells to break down fat and obtain energy from stored fat reserves (Pkala et al., 2011). L-carnitine is mainly produced in the liver and kidneys. In the production process, vitamin C, iron ions, and niacin also play an important role (Brass, 2004).

Carnitine is a molecule that has 2 enantiomers, namely dextra (D) and levo (L). Of the 2 enantiomers, only the L-carnitine form has physiological activity. L-carnitine has a high binding energy with carboxylic acids which produces acetylcarnitine derivatives (Reuter & Evans, 2012). L-carnitine is an amino acid which is a choline analogue, namely a hydrophilic quaternary amine which has an effect on several physiological activities in the body. In lipid metabolism, L-carnitine acts as a coenzyme used for fatty acid oxidation and as a transporter of long chain fatty acids from the cytosol into the mitochondrial matrix so that the fatty acid beta oxidation process can then be carried out(Cicero et al., 2020). L-carnitine can increase muscle mass and its oxidative activity can be seen in its ability to reduce oxidative stress (Kraemer et al., 2008a). Additionally, L-carnitine may be associated with reduced insulin resistance through a mechanism that could be linked to the nitrate oxidation pathway (Xu et al., 2017).

L-carnitine supplementation can increase lipid oxidation, save glycogen stores in muscles so that it can improve exercise performance and reduce fat (Stephens et al., 2007), (Huang Kevin Owen, 2013) It has been estimated that the total carnitine present in the human body is around 300mg/kg with around 95 % stored in heart and skeletal muscle cells. The amount of carnitine in plasma is only around 0.5% of the total carnitine in the body (Flanagan et al., 2010b). L L-carnitine can be obtained not only from supplements, but can be obtained from foods such as red meat, fish, and products containing milk (Flanagan et al., 2010a), (Mingrone, 2004), (Kraemer et al., 2008b).

L-carnitine has many effects on metabolism in athletes' bodies, especially its effects on blood pressure and VO2 max in athletes. L-carnitine can reduce blood pressure by increasing fatty acid oxidation and reducing superoxide production so that it can increase the availability of nitric oxide and cause a decrease in blood pressure (O'Brien et al., 2010). Meanwhile, the effect of carnitine is in stabilizing the ratio of acetyl coenzyme to free coenzyme and preventing the accumulation of lactate and causing an increase in VO2 max (Kashef & Saei, 2017). The aim of this review is to look at the effect of consuming L-carnitine on reducing blood pressure and increasing

VO2 max in athletes who exercise, where in previous studies there have been no reviews explaining the two functions of carnitine in one review.



The results of searches carried out using electronic databases, namely Pubmed, ScienceDirect and Scopus, resulted in 895 articles. There were 115 articles that

matched the title and abstract. In the screening process, 60 articles were found that met the inclusion criteria, however there were 20 articles that were incomplete so they could not proceed to the eligibility stage. There were 40 articles that were then subjected to a feasibility test and there were 25 texts that met the exclusion criteria, namely

15 observational studies, 10 studies conducted on animals, and 10 studies that were not randomized controlled trials. The final results obtained were 5 articles that could be used in the review.

Blood pressure is an important health factor according to the World Health Organization (WHO). According to data available worldwide, increased blood pressure is estimated to cause 7.5 million, which is around 12.8% of total deaths (Nawata et al., 2017).

Oral L-carnitine supplementation can improve cardiovascular risk factors such as arterial hypertension, insulin resistance, impaired glucose tolerance, and hypoadiponectinemia in groups of subjects with increased cardiovascular risk and was found to be well tolerated (Ruggenenti et al., 2009a). Carnitine levels in the body will decrease little by little in ischemic conditions, so it is necessary to consume exogenous carnitine in the form of supplementation in order to replenish carnitine levels in the heart myocardium (Wang et al., 2018).

There are several studies that show the effect of consuming L-carnitine on blood pressure, but some studies show the opposite. Research conducted by Ruggenenti et al showed that L-carnitine supplementation of 2 grams/day could reduce systolic blood pressure without changing diastolic blood pressure, whereas research conducted by Talenezhad et al and Parvanova et al with the same dose did not show any effect on blood pressure parameters (Ruggenenti et al., 2009b), (Parvanova et al., 2018), (Talenezhad et al., 2020).

In a meta-analysis conducted by Askarpour (2019), analyzing 10 articles from 2006-2018, it was shown that L-carnitine had a significant effect on reducing diastolic blood pressure, but not significantly on systolic (Askarpour et al., 2019). However, this meta-analysis has limitations in that this meta-analysis takes a diverse population ranging from hemodialysis patients to patients with diabetes mellitus. So the effects of carnitine supplementation can still be greatly influenced by the patient's condition. L-carnitine supplementation at a dose of more than 2 grams per day shows a significant reduction in diastolic pressure when compared with a dose of less than 2 grams per day. High doses of L-carnitine show an increase in serum trimethylamine-N-oxide (TMAO) which in this case can reduce blood pressure (Koeth et al., 2013), (Iaccarino et al., 2022)

In athletes supplemented with 1 gram of L-carnitine, plasma levels remained high after exercise and provided a significant reduction in blood pressure when compared with athletes without supplementation (Fielding et al., 2018). A reduction in blood pressure was also found with L-carnitine use at week 6 and 9th. This is indicated by the presence of significant wingate and metabolic responses, especially at week 9 (Kim et al., 2018). Research conducted by Choi on the effects of L-carnitine on metabolic syndrome biomarkers showed that administration of an average of 2 g/day (0.75 – 3

grams/day) over an average period of 12 weeks provided a significant reduction in systolic pressure (Choi et al., 2020) .

However, if we look at individuals who are obese (in terms of BMI), the group that received L-carnitine intervention experienced a decrease in diastolic blood pressure. This result can be caused by weight loss caused by L-carnitine which can improve physiological factors that influence blood pressure (Cohen, 2017)

On the other hand, research conducted by Anaraki et al shows that L-carnitine supplementation does not cause significant changes in systolic or diastolic. Based on the subgroup analysis carried out, there was a significant reduction in diastolic blood pressure of 1.59 mmHg in participants with an initial BMI >30kg/m2 (Anaraki et al., 2024)

Effects on VO2max and endurance

VO2 max is the highest average oxygen used when the body is working. This makes VO2 max a parameter that can define the ability of the cardiorespiratory system to transport oxygen to various body tissues (Snell et al., 2007).

Increased VO2 max levels are a sign of improvement in cardiovascular fitness in athletes and non-athletes as well as patients. In addition, decreased heart rate during rest or exercise is a prominent physiological symptom and increases aerobic fitness (Maughan, 2002).

L-carnitine has the potential to reduce chemical damage to tissue and aid the repair and remodeling process of muscle tissue(Kraemer et al., 2008c). Carnitine is an important factor for the transport of acetyl-coenzyme A and is involved in the oxidation of fatty acids in the liver and kidneys. This gives rise to the main hypothesis that a potential increase in carnitine concentration in skeletal muscle will lead to an increase in fatty acid transport and oxidation, increasing oxygen consumption (VO2) and also endurance (endurance performance) (Longo et al., 2016), (Kraemer et al., 2008d). Fat oxidation in the body requires a higher amount of oxygen compared to carbohydrates. In the cardiovascular system, more oxygen should be received in the muscles. L-carnitine can increase oxygen consumption and also lipid oxidation by stimulating the pyruvate dihydrogenase complex and the entry of pyruvate into the beta oxidation pathway [3].

Exercise in athletes can be classified into low to moderate intensity (<70% VO2max) and high intensity (>75% VO2 max)(Scribbans et al., 2016).When an athlete performs low intensity exercise, muscle aerobic metabolism will dominate, lactate does not accumulate and exercise can be maintained On the other hand, at a high level of work, lactate will accumulate in the muscles and blood, causing fatigue quickly (Gnoni et al., 2020).

L-carnitine which has an effect on VO2 max still has many different opinions because of its varying significance. A previous study reported that long-term oral L-carnitine supplementation of 2 grams per day (4 weeks) could result in an increase in VO2 max in elite and amateur athletes.

Five studies analyzed chronic supplementation (4–24 weeks) and six studies used acute administration (<7 days). The dose of this chronic supplementation varies from 1 to 3 g/day; in acute supplementation, the oral L-carnitine supplementation dose ranges from 3 to 4 g. On the one hand, the effects of oral L-carnitine supplementation on high-intensity exercise performance variables were analyzed in nine studies (Mielgo-Ayuso et al., 2021).

	Author	Population	Intervention	Output
Accute (7 days)	Wall et al., 2011 (Wall et al., 2011)	14 athletes	4 gram/day of *L-carnitine* with carbohydrate twice a day. Intervention : 24 weeks	Weeks-12 : no changes Weeks- 24: significant effects (p<0,05)
	Shannon et al., 2018 (Shannon et al., 2018)	14 male athletes	4,5-gram of *L-carnitine* with 160 gram carbohydrate twice a day (once on breakfast and second 4 hours later) Intervention : 24 weeks	There is no significant effects during intervention
Chronic (4-24 weeks)	Smith et al., 2008 (Smith et al., 2008)	32 athletes (9 males and 23 women)	1 gram/day: n=11 3 gram/day: n=12 Intervention: 8 weeks	There is no significant effects during intervention
	Chun 2011 (Chun et al., 2011)	36 soccer athletes	2-6 gram per day, devided into 6 grup Intervention : 4 weeks	There is significant increasing of VO_2 max (p<0,05)
	Burrus et al., 2018 (Burrus et al., n.d.)	10 athletes (27 years old)	3 gram of L-carnitine + 200 ml of water 3 hour before exercise.	There is no significant effects during intervention

In a study conducted by Kashef and Saei in 2017, the group given L-carnitine supplementation had a higher VO2 max level when compared to placebo and showed a negative correlation between blood lactate and VO2 max. A decrease in lactate levels in the blood can occur due to fatty acid oxidation and improve performance from exercise. Current studies show that L-carnitine supplementation before exercise can reduce blood lactate and increase VO2 max in young men and does not affect blood glucose and heart rate after fatigue testing (Kashef & Saei, 2017)

Consuming L-carnitine supplements in the short and long term also has different effects on athletes. A study conducted using L-carnitine supplements chronically, namely 2 grams per day for 24 weeks, showed that there were no significant results on VO2 max when tested using a bicycle ergometer ($p > 0.05$) (Shannon et al., 2018). carried out using L-carnitine at a dose of 2 grams per day for 24 weeks and a 30 minute test was carried out and it was found that there was a significant increase.

Endurance is an athlete's resistance capacity to fatigue and this endurance will determine the period limit when a certain activity with a certain intensity is carried out. The results show that L-carnitine supplementation has a positive effect on the athletes' running speed and affects lactic acid. Lactic acid is related to increasing a person's running speed. Intake of 3–4 grams of L-carnitine before exercise can delay the formation of lactate in the blood, resulting in fatigue occurring more slowly (Orer & Guzel, 2014)

CONCLUSION

L-carnitine has more effect on a person's diastolic than systolic at doses of more than 2 grams/day. Meanwhile, the effect on VO2 max was seen in long-term use of 2 grams for 24 weeks and found a significant increase in VO2 max ($p<0.05$). L-carnitine does have an effect on blood pressure, VO2 max and is also correlated with endurance, but until now there is still a need for more research to show that the effects produced by L-carnitine are significant both on blood pressure and VO2 max in athletes.

REFERENCES

Anaraki, S. R., Aali, Y., Nikbaf-Shandiz, M., Rasaei, N., Khadem, A., Bahari, H., Khalse, Z., Rastgoo, S., Shiraseb, F., & Asbaghi, O. (2024). The Effects of L-Carnitine Supplementation on Blood Pressure in Adults: A Systematic Review and Dose-response Meta-analysis. In *Clinical Therapeutics* (Vol. 46, Issue 2, pp. e73–e86). Elsevier Inc. https://doi.org/10.1016/j.clinthera.2023.11.002

Askarpour, M., Hadi, A., Bozorg, A. D. K., & ... (2019). Effects of l-carnitine supplementation on blood pressure: a systematic review and meta-analysis of randomized controlled trials. *Journal of Human …*. https://www.nature.com/articles/s41371-019-0248-1

Bacurau, R. F. P., Navarro, F., Bassit, R. A., Meneguello, M. O., Santos, R. V. T., Almeida, A. L. R., & Rosa, L. F. B. P. C. (2003). *APPLIED NUTRITIONAL INVESTIGATION Does Exercise Training Interfere With the Effects of L-Carnitine Supplementation?*

Brass, E. P. (2004). Carnitine and sports medicine: Use or abuse? *Annals of the New York Academy of Sciences*, *1033*, 67–78. https://doi.org/10.1196/annals.1320.006

Burrus, B. M., Moscicki, B. M., Matthews, T. D., & Paolone, V. J. (n.d.). *The Effect of Acute L-carnitine and Carbohydrate Intake on Cycling Performance*. http://www.intjexersci.com

Choi, M., Park, S., & Lee, M. (2020). L-carnitine's effect on the biomarkers of metabolic syndrome: A systematic review and meta-analysis of randomized controlled trials. In *Nutrients* (Vol. 12, Issue 9, pp. 1–12). MDPI AG. https://doi.org/10.3390/nu12092795

Chun, Y., Lee, K., Kang, S., Lee, N., & Kim, J. (2011). Influence of L-Carnitine intake for maximal exercise performance and fatigue recovery exercise athletes: based on elite soccer players. *The Journal of Exercise Nutrition and Biochemistry*, *6*(1), 28–34. https://doi.org/10.5717/jenb.2011.15.1.28

Cicero, A. F. G., Colletti, A., Von Haehling, S., Vinereanu, D., Bielecka-Dabrowa, A., Sahebkar, A., Toth, P. P., Reiner, Ž., Wong, N. D., Mikhailidis, D. P., Ferri, C., & Banach, M. (2020). Nutraceutical support in heart failure: A position paper of the International Lipid Expert Panel (ILEP). In *Nutrition Research Reviews* (Vol. 33, Issue 1, pp. 155–179). Cambridge University Press. https://doi.org/10.1017/S0954422420000049

Cohen, J. B. (2017). Hypertension in Obesity and the Impact of Weight Loss. In *Current Cardiology Reports* (Vol. 19, Issue 10). Current Medicine Group LLC 1. https://doi.org/10.1007/s11886-017-0912-4

Fielding, R., Riede, L., Lugo, J. P., & Bellamine, A. (2018). L-carnitine supplementation in recovery after exercise. In *Nutrients* (Vol. 10, Issue 3). MDPI AG. https://doi.org/10.3390/nu10030349

Flanagan, J. L., Simmons, P. A., Vehige, J., Willcox, M. D., & Garrett, Q. (2010a). Open Access REVIEW BioMed Central Role of carnitine in disease. In *Nutrition & Metabolism* (Vol. 7). http://www.nutritionandmetabolism.com/content/7/1/30

Flanagan, J. L., Simmons, P. A., Vehige, J., Willcox, M. D., & Garrett, Q. (2010b). Role of carnitine in disease. In *Nutrition and Metabolism* (Vol. 7). https://doi.org/10.1186/1743-7075-7-30

Gnoni, A., Longo, S., Gnoni, G. V., & Giudetti, A. M. (2020). Carnitine in human muscle bioenergetics: Can carnitine supplementation improve physical exercise? In *Molecules* (Vol. 25, Issue 1). MDPI AG. https://doi.org/10.3390/molecules25010182

Huang Kevin Owen, A. (2013). Acute Topics in Sport Nutrition. In *Med Sport Sci. Basel, Karger* (Vol. 59).

Iaccarino, G., Yoshikawa, M., Papandreou, C., Mascarenhas, P., Maloberti, A., Wang, H., & Zhang, Z. (2022). *Trimethylamine N-oxide and its precursors in relation to blood pressure: A mendelian randomization study*.

Karlic, H., & Lohninger, A. (2004). Supplementation of L-carnitine in athletes: Does it make sense? In *Nutrition* (Vol. 20, Issues 7–8, pp. 709–715). https://doi.org/10.1016/j.nut.2004.04.003

Kashef, M., & Saei, M. A. (2017). Acute Effect of L-Carnitine Supplements on Lactate, Glucose, Saturated Oxygen and VO2max Variations in Young Males. *International Journal of Basic Science in Medicine*, *2*(1), 46–51. https://doi.org/10.15171/ijbsm.2017.10

Kementrian Kesehatan RI. (2019). *UJI KLINIK*.

Kim, N., Kim, J., Lim, K., & Park, J. (2018). Role of dihydrotestosterone in whole-body energy utilization during acute running exercise in mice. *Journal of Exercise Nutrition & Biochemistry*, *22*(2), 7–11. https://doi.org/10.20463/jenb.2018.0010

Koeth, R. A., Wang, Z., Levison, B. S., Buffa, J. A., Org, E., Sheehy, B. T., Britt, E. B., Fu, X., Wu, Y., Li, L., Smith, J. D., Didonato, J. A., Chen, J., Li, H., Wu, G. D., Lewis, J. D., Warrier, M., Brown, J. M., Krauss, R. M., … Hazen, S. L. (2013). Intestinal microbiota metabolism of l-carnitine, a nutrient in red meat, promotes atherosclerosis. *Nature Medicine*, *19*(5), 576–585. https://doi.org/10.1038/nm.3145

Kraemer, W. J., Volek, J. S., & Dunn-Lewis, C. (2008a). L-Carnitine Supplementation: Influence upon Physiological Function. In *Sports Med. Rep* (Vol. 7, Issue 4). www.acsm-csmr.org

Kraemer, W. J., Volek, J. S., & Dunn-Lewis, C. (2008b). L-Carnitine Supplementation: Influence upon Physiological Function. In *Sports Med. Rep* (Vol. 7, Issue 4). http://journals.lww.com/acsm-csmr

Kraemer, W. J., Volek, J. S., & Dunn-Lewis, C. (2008c). L-Carnitine Supplementation: Influence upon Physiological Function. In *Sports Med. Rep* (Vol. 7, Issue 4). www.acsm-csmr.org

Kraemer, W. J., Volek, J. S., & Dunn-Lewis, C. (2008d). L-Carnitine Supplementation: Influence upon Physiological Function. In *Sports Med. Rep* (Vol. 7, Issue 4). www.acsm-csmr.org

Longo, N., Frigeni, M., & Pasquali, M. (2016). Carnitine transport and fatty acid oxidation. *Biochimica et Biophysica Acta - Molecular Cell Research*, *1863*(10), 2422–2435. https://doi.org/10.1016/j.bbamcr.2016.01.023

Maughan, R. (2002). The athlete's diet: nutritional goals and dietary strategies. *Proceedings of the Nutrition Society*, *61*(1), 87–96. https://doi.org/10.1079/pns2001132

Mielgo-Ayuso, J., Pietrantonio, L., Viribay, A., Calleja-González, J., González-Bernal, J., & Fernández-Lázaro, D. (2021). Effect of acute and chronic oral l-carnitine supplementation on exercise performance based on the exercise intensity: A systematic review. In *Nutrients* (Vol. 13, Issue 12). MDPI. https://doi.org/10.3390/nu13124359

Mingrone, G. (2004). Carnitine in type 2 diabetes. *Annals of the New York Academy of Sciences*, *1033*, 99–107. https://doi.org/10.1196/annals.1320.009

Nawata, K., Matsumoto, A., Kajihara, R., & Kimura, M. (2017). Evaluation of the Distribution and Factors Affecting Blood Pressure Using Medical Checkup Data in Japan. *Health*, *09*(01), 124–137. https://doi.org/10.4236/health.2017.91009

O'Brien, D., Chunduri, P., Iyer, A., & Brown, L. (2010). L-carnitine attenuates cardiac remodelling rather than vascular remodelling in deoxycorticosterone acetate-salt hypertensive rats. *Basic and Clinical Pharmacology and Toxicology*, *106*(4), 296–301. https://doi.org/10.1111/j.1742-7843.2009.00480.x

Orer, G. E., & Guzel, N. A. (2014). *THE EFFECTS OF ACUTE L-CARNITINE SUPPLEMENTATION ON ENDURANCE PERFORMANCE OF ATHLETES*. www.nsca.com

Parvanova, A., Trillini, M., Podestà, M. A., & ... (2018). Blood Pressure and Metabolic Effects of Acetyl-l-Carnitine in Type 2 Diabetes: DIABASI Randomized Controlled Trial. *Journal of the …*. https://academic.oup.com/jes/article-abstract/2/5/420/4947766

Pkala, J., Patkowska-Sokoa, B., Bodkowski, R., Jamroz, D., Nowakowski, P., Lochyski, S., & Librowski, T. (2011). L-Carnitine-Metabolic Functions and Meaning in Humans Life. In *Current Drug Metabolism* (Vol. 12).

Reuter, S. E., & Evans, A. M. (2012). *Carnitine and Acylcarnitines Pharmacokinetic, Pharmacological and Clinical Aspects*.

Ruggenenti, P., Cattaneo, D., Loriga, G., Ledda, F., Motterlini, N., Gherardi, G., Orisio, S., & Remuzzi, G. (2009a). Ameliorating hypertension and insulin resistance in subjects at increased cardiovascular risk: Effects of acetyl-l-carnitine therapy. *Hypertension*, *54*(3), 567–574. https://doi.org/10.1161/HYPERTENSIONAHA.109.132522

Ruggenenti, P., Cattaneo, D., Loriga, G., Ledda, F., Motterlini, N., Gherardi, G., Orisio, S., & Remuzzi, G. (2009b). Ameliorating hypertension and insulin resistance in subjects at increased cardiovascular risk: Effects of acetyl-l-carnitine therapy. *Hypertension*, *54*(3), 567–574. https://doi.org/10.1161/HYPERTENSIONAHA.109.132522

Scribbans, T. D., Vecsey, S., Hankinson, P. B., Foster, W. S., & Gurd, B. J. (2016). Exercise training. In *International Journal of Exercise Science* (Vol. 9, Issue 2). http://www.intjexersci.com

Shannon, C. E., Ghasemi, R., Greenhaff, P. L., & Stephens, F. B. (2018). Increasing skeletal muscle carnitine availability does not alter the adaptations to high-intensity interval training. *Scandinavian Journal of Medicine and Science in Sports*, *28*(1), 107–115. https://doi.org/10.1111/sms.12885

Smith, W. A., Fry, A. C., Tschume, L. C., & Bloomer, R. J. (2008). Effect of Glycine Propionyl-L-Carnitine on Aerobic and Anaerobic Exercise Performance. In *International Journal of Sport Nutrition and Exercise Metabolism* (Vol. 18).

Snell, P. G., Stray-Gundersen, J., Levine, B. D., Hawkins, M. N., & Raven, P. B. (2007). Maximal oxygen uptake as a parametric measure of cardiorespiratory capacity.

Medicine and Science in Sports and Exercise, *39*(1), 103–107. https://doi.org/10.1249/01.mss.0000241641.75101.64

Stephens, F. B., Constantin-teodosiu, D., & Greenhaff, P. L. (2007). New insights concerning the role of carnitine in the regulation of fuel metabolism in skeletal muscle. In *Journal of Physiology* (Vol. 581, Issue 2, pp. 431–444). https://doi.org/10.1113/jphysiol.2006.125799

Talenezhad, N., Mohammadi, M., & ... (2020). Effects of l-carnitine supplementation on weight loss and body composition: A systematic review and meta-analysis of 37 randomized controlled clinical trials with dose …. *Clinical Nutrition …*. https://www.sciencedirect.com/science/article/pii/S240545772030053X

Wall, B. T., Stephens, F. B., Constantin-Teodosiu, D., Marimuthu, K., Macdonald, I. A., & Greenhaff, P. L. (2011). Chronic oral ingestion of l-carnitine and carbohydrate increases muscle carnitine content and alters muscle fuel metabolism during exercise in humans. *Journal of Physiology*, *589*(4), 963–973. https://doi.org/10.1113/jphysiol.2010.201343

Wang, Z. Y., Liu, Y. Y., Liu, G. H., Lu, H. Bin, & Mao, C. Y. (2018). L-Carnitine and heart disease. In *Life Sciences* (Vol. 194, pp. 88–97). Elsevier Inc. https://doi.org/10.1016/j.lfs.2017.12.015

Xu, Y., Jiang, W., Chen, G., Zhu, W., Ding, W., Ge, Z., Tan, Y., Ma, T., & Cui, G. (2017). L-carnitine treatment of insulin resistance: A systematic review and meta-analysis. In *Advances in Clinical and Experimental Medicine* (Vol. 26, Issue 2, pp. 333–338). Wroclaw University of Medicine. https://doi.org/10.17219/acem/61609