Quadros et al., Vitam Miner 2016, 5:1

Vitamins & Minerals

Mini Review Open Access

Ascorbic Acid and Performance: A Review

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Abstract

Purpose: Review of the evidence which supports the consumption of vitamin C for sportsmen and athletes aiming improvement performance. Data synthesis: Vitamin C is an essential micronutrient with several important biological functions. In addition to being considered a potent antioxidant that eliminates reactive oxygen and nitrogen species. Among other functions, vitamin C reduces the symptoms of colds and flu, accelerating the recovery process and has an anti-catabolic effect. This effect has fundamental importance for the physically active. Considering that vitamin C participates as a cofactor in carnitine biosynthesis, steroid hormones and neurotransmitters, it has been established the idea that the need for this nutrient would increase for people engaged in strenuous exercise or frequent stress. Because of this, this paper aims to investigate the role of this micronutrient in performance.

Material and methods: We searched the published scientific literature for randomized controlled trials of adult human subjects reporting vitamin C intake and training, besides animal models and literature review about the topic. Twenty-eight papers since 2000 were identified by searches of PubMed, with the search terms “ascorbic acid”, “bioavailability”, “oxidative stress”, “performance”, “free radicals” “supplementation”, “toxicity” and “vitamin C”, ensuring recent knowledge about ascorbic acid.

Conclusions: The importance of vitamin C in the diet is indisputable, but more research is needed to clarify whether supplementation of this micronutrient actually leads to performance optimization.

Keywords: Vitamin C; Bioavailability; Oxidative stress; Supplementation; Toxicity

Introduction

Regular physical activity associated with a balanced diet can be an important factor in health promotion. However, frequent high intensity or exhaustive exercises can increase susceptibility to injury, promote chronic fatigue and overtraining, partially due to the high synthesis of reactive oxygen species [1].

The search for improvement in the performance of athletes and sportsmen has been discussed in order to find nutrients that optimize the results without causing toxicity to the consumer. Vitamin C is an essential micronutrient with many important biological functions, and a cofactor for the biosynthesis of collagen, carnitine, neurotransmitters, peptide hormones and has an anti-catabolic effect and also accelerates muscle recovery [2,3].

A high vitamin C food sources diet is based on citrus/acid fruits or their juices (cherry, orange, pineapple, cashew, guava, mango, passion fruit, lemon), berries, green and red peppers, tomatoes, broccoli and leafy vegetables such as spinach [4]. The recommendation of vitamin C is easily achieved since we consume at least one of its food source daily. The RDA’s of vitamin C are from 90 mg to 75 mg for men and women, respectively. The absorption of vitamin C is about 70% to 90% of the ingested intake when the amount is in the range of 30 to 180 mg / day. However, when the amount is around 1 g absorption is reduced by 50% [5].

The latest recommendations of vitamin C, according to the National Academy of Sciences, are 75 mg for men and 90 mg for men, and smokers may require 35 mg extras, the maximal daily tolerated intake is 2,000 mg [4]. Deruelle and Baron (2008), reports that the recommended daily allowance (RDA) for vitamin C is smaller than the body needs. In fact, it does not seem to guarantee the protection of true health and it seems to be difficult to achieve an effective dose of vitamin C only through the consumption of food [6].

According to Gomes et al. vitamin C is also a strong reducing agent, due to its easiness of donating electrons, with important antioxidant properties. It can inactivate a wide variety of reactive species minimize damage to body tissues [7]. Vitamin C, among other effects, reduces the symptoms of colds and flu, accelerating the process of recovery and has an anti-catabolic effect. This anti-catabolic effect is essential for bodybuilders [3].

Antioxidant action and physical activity

Ascorbic acid is considered a potent antioxidant, which eliminates reactive oxygen and nitrogen [8]. Antioxidants are substances which contribute to reduce the effects of stress and lack of oxygen caused by exercise, forming complexes which reduce free radical producing reactions. Free radicals are unstable molecules, without a pair of electrons in their outer orbits and are highly reactive and can cause traumatic processes in the tissues caused by different reactions. Intense and continuous physical exercise produces free radicals, which can cause muscle damage followed by the inflammatory process, restricting muscle function [9].

Experimental studies suggest an important role of oxidative stress in atherogenesis: damage mediated by free radicals inducing oxidative changes in low-density cholesterol particles that initiate and promote atherosclerotic changes. This process can be reversed or prevented by the intake of antioxidants [10]. Considering that ascorbic acid participates as a cofactor in carnitine biosynthesis, steroid hormones and neurotransmitters, it was established the idea that the requirements

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Received February 14, 2016; **Accepted** March 04, 2016; **Published** March 11, 2016

Citation: Quadros L, Brandao I, Longhi R (2016) Ascorbic Acid and Performance: A Review. Vitam Miner 5: 136.

of this nutrient would be increased among people engaged in strenuous exercise or frequent stress. But it seems that there is no evidence to support this hypothesis [5].

The reasons of the increased production of free radicals during exercise have not been fully clarified. Although several mechanisms have been identified, there remains a lack of understanding on how each of them contributes to the total quantity of oxidative stress produced. For example, although the general consensus is that, during exercise, the production of reactive species occurs mainly through the muscle contraction (skeletal and cardiac), other mechanisms such as inflammation and increased release of catecholamines which can occur with exercise also play an important role in the generation of reactive species [7].

Regarding the intense exercise, both aerobic and anaerobic exercise can result in increased production of free radicals, but the acute oxidative stress cannot always be evaluated by athletes. The production of reactive oxygen species is positively dependent on the load (intensity × duration) of the exercise. It is suggested that high reactive oxygen species produced by intense series of exercise can be harmful to the immune system. However, chronic exercise produces physiological adaptations capable of regulating the antioxidant system [7].

Important to highlight that vitamin C controls the production of cortisol. It is a hormone released during stress conditions and/or high physical efforts are conducted, as a heavy training, this hormone is an antagonist to testosterone, in fact, the release of cortisol suppresses the natural testosterone produced in our body, then it begins a dispute between these two hormones; while there is a catabolic effect of cortisol, there is an anabolic effect of testosterone [3]. Peter et al. proposed that vitamin C-associated decrease in serum cortisol might result from inhibition of enzymes involved in steroidogenesis, in their paper were evaluated 29 runners and the results showed serum cortisol was significantly lower in the vitamin C group [11]. Corroborating, Padayatty et al. in their research comment that the essential adrenocorticotrophic hormone (ACTH) secreted by the pituitary gland stimulates adrenal glands to synthesize and secrete cortisol. In animals, ACTH also causes vitamin C loss from adrenals. Adrenal glands are rich in vitamin C, with concentrations as high as 10 mmol/L, for these reasons, vitamin C and stress in humans have long been associated, despite a lack of direct evidence for such a link [12]. According the available literature there are some different results in relation to oxidative stress rates as the result of exercise performance. This is understandable, because a variety of factors can influence the oxidative rate, such as hired muscle groups, the contraction modes, exercise intensity, exercise duration, and the population exercising [7].

Effect of antioxidant supplementation

The literature shows that the highest intake of vitamin C than the RDA is safe. Therefore, in order to gain health and preventing a number of diseases, it is suggested that, in this situation, the supplemental vitamin C is required, in order to ensure optimal allowance of vitamin C, it is advisable 1 g daily vitamin C supplementation, accompanied by a diet with fruits and vegetables [6]. On the other hands, Palmer et al. found that supplementation with 1,500 mg vitamin C/day for seven days before and during an ultra-marathon did not attenuate oxidative stress after the race [13]. There is a lack of direct evidence ensuring that vitamin C is beneficial to performance, and there is no convincing evidence to suggest that antioxidant supplementation enhances exercise-training adaptations, which is an important factor to avoid supplementation in high dosage [14].

A study determined the effects of four weeks vitamin C supplementation (1000 mg /day), daily throughout the training period, in the performance of moderately trained humans (7 men in the placebo group aged 23 years and 8 males men in the supplemented group aged 21 years), in an interval race protocol of high intensity lasting four weeks was implemented. The training improved both VO2 max and performance, measured by various physical fitness tests. In addition, and as expected, the training increased fat oxidation rate and decreased carbohydrate oxidation rate during acute exercise. In this case vitamin C supplementation for four weeks of interval training did not affect improvements induced by training on exercise performance in humans [15].

Thompson et al. from a non-habitual exercise session, evaluated the effect of two weeks of supplementation with vitamin C on recovery. The supplemented group received two doses of 200 mg of vitamin C/day, and two weeks after the start of supplementation, the subjects underwent an intense and prolonged exercise protocol. The concentration of creatine kinase and myoglobin was not altered by supplementation. However, supplementation attenuated muscle pain, benefiting from the recovery of muscle function [16]. In another study, Thompson et al. investigated the effect of post-exercise vitamin C supplementation on the recovery from the performance of an intense, prolonged and unusual workout. Immediately after the activity, the supplemented group took 200 mg of vitamin C. This nutritional intervention was repeated again on the same day and in the morning and evening of the following two days. The concentration of vitamin C in the supplemented group increased plasma one hour after the end of the exercise and remained elevated for three days after exercise. The concentrations of creatine kinase and myoglobin, however, were not affected by supplementation, and both the pain and the recovery of muscle function did not differ between groups [17].

According, Carr et al. the results showed that the intake of this nutrient within the preset daily recommendations was enough to saturate the muscle tissue, and not dietary supplementation was unnecessary for daily replenishment [2].

Studies have recently shown that antioxidant supplementation can interfere in the cellular signaling induced by exercise in skeletal muscle fibers. For example, Gomez-Cabrera investigated the effect of vitamin C on training efficiency in rats and in humans. In the human study, 14 were trained for 8 week, 5 of the men were supplemented daily with an oral dose of 1 g vitamin C and the animal study, and 24 male Wistar rats were exercised under for 3 and 6 week. In their results, the administration of vitamin C significantly ($p=0.014$) hampered endurance capacity. The adverse effects of vitamin C may result from its capacity to reduce the exercise-induced expression of key transcription factors involved in mitochondrial biogenesis, prevented the exercise-induced expression of cytochrome C (a marker of mitochondrial content) and of the antioxidant enzymes superoxide dismutase and glutathione peroxidase (oral vitamin C). Interestingly, performance increased resistance to a greater extent in the animals treated with placebo compared with animals treated with Vitamin C. Thus, supplementation with high doses of vitamin C to decrease certain adaptations induced endurance training skeletal muscles [18]. In fact, high doses of isolated antioxidants should be used with caution in individuals who are simultaneously engaged in resistance training [19].

Likewise, a high-intensity physical activity and/or duration can be toxic, because it can generate free radicals from the increased oxygen consumption by mitochondria. It is believed that this excess of free radicals can lead to damage on the muscle membranes. However, the human organism has several endogenous defense mechanisms to neutralize free radicals and enzymes: superoxide dismutase, glutathione peroxidase and catalase. On the other hand, regular physical activity increases the effectiveness of these endogenous mechanisms, collaborating so that even after strenuous physical activity, there is no oxidative damage. Nevertheless, it is a common practice among athletes using extra doses of vitamins, especially C and E for its antioxidant properties [20]. It´s important to highlight that under normal conditions about 1% of ROS daily escape the control of the endogenous AOX defenses and contribute to peroxidative damage to surrounding tissues, and thereby to aging [21].

Vitamin C is also known to regenerate other antioxidants such as vitamin E, glutathione, back to its reducing condition. Thus, there is the maintenance of a balanced network antioxidants [22]. Higashida et al. studied the combined effect of vitamin C (750 mg / kg body weight / day) and vitamin E (150 mg kg body weight / day) supplemented on the adaptive responses training-induced muscle mitochondria and sensitivity to insulin in rats. Based on the results of this study, supplementation of vitamin C and E does not have an inhibitory effect or a promoter effect on the adaptive responses related to mitochondria and glucose metabolism in skeletal muscle to chronic exercise [23].

Ryan et al. explored the effects of chronic electrical stimulation combined with supplementation of vitamin C and vitamin E in homeostasis and muscle function in young rats (7 males by age group up to 3 months) and old mice (7 males per group aged up 30 months). The untrained rats were subjected to 80-concentric maximum eccentric actions per session, three times a week for 4.5 weeks. Vitamin C supplementation (20 g / kg body weight/day) and vitamin E (30 g kg body weight /day) supplemented started one week before the first session of electrical stimulation. In summary, the supplemental vitamin C and E resulted in reduction of the oxidative stress induced by electrical stimulation and concentric work better in old rats, but not in young rats [24].

Another study examined the effect of antioxidant vitamins on the regulation of interleukin-6 expression in the muscles and the circulation in response to acute exercise before and after high intensity endurance training. Twenty-one healthy young men were divided into two groups: VT (vitamin C and E, n=11) and placebo (PL, N=10). In one of the trials it was conducted acute bike exercise (1 h at 65% of maximum power), before and after 12 weeks of progressive resistance exercise training. The effects of the exercise was measured by the concentration of vitamin C, α-tocopherol and interleukin-6 (IL6), cortisol, protein carbonyls concentrations in plasma, SOD, GPx IL-6 mRNA, malondialdehyde (MDA) concentration in skeletal muscle biopsies. The results comment that supplementation might attenuate the acute exercise-induced increase in plasma IL-6, such supplementation does not seem to further decrease IL-6 levels after 12 wk of vitamin supplementation combined with endurance training. In conclusion, the results indicate that, although the supplemental vitamin C and E can mitigate increases in plasma IL-6 induced by exercise, there is no clear additive effect when it is combined with resistance training [25].

In their study, Theodorou et al. evaluated a group of men that received daily oral supplements of vitamin C and vitamin E (n=14) and placebo (n=14) for 11 weeks (starting 4 weeks before pre-training exercise testing and continued until the post-training exercise test). After the baseline test, the subjects performed an eccentric workout 2 times / week for 4 weeks. Before and after chronic eccentric exercise, subjects were submitted to an acute eccentric exercise session. Physiological measurements were performed and samples were collected blood samples and muscle biopsy. The results did not support any effect of antioxidant supplementation. The complete lack of any effect on measures of physiological and biochemical results used, raises questions about the validity of the use of oral antioxidant supplementation as a redox muscle modulator and redox status in healthy humans [26].

By reasons above, it is believed that, due to the excess is excreted, excessive consumption is innocuous. There is no verifiable evidence that the intake of vitamin C is carcinogenic and teratogenic. Review on the subject showed that high doses of vitamin C have low toxicity. Adverse effects were demonstrated with very high doses, above 3 g/ day, which include diarrhea, gastrointestinal disturbances, increased oxalate excretion, renal stone formation and increased urinary excretion of uric acid, pro-oxidative effects and effects abstinence (this effect refers to the fact that the regular person the system to absorb small part of high doses available; when the person stops taking the high doses, the body does not absorb the small amount that becomes ingested) [5].

Conclusions

Despite conflicting data, the importance of vitamin C as an antioxidant is well established, considering the recommended doses, usually achieved by feeding. In addition to the capture of free radicals, cell culture studies demonstrate that vitamin C can alter the expression of genes involved in the inflammatory response, apoptosis, and cell differentiation [27].

There is controversy regarding the results associated with vitamin C and E, two popular antioxidant nutrients. Recent evidence suggests that the exogenous administration of these antioxidants may be detrimental to performance. The available studies that used animal models and humans provide conflicting results on the efficacy of the supplementation of vitamin C and E at least in part due to methodological differences in assessing oxidative stress. Based on contradictory evidence on the effects of increased intake of vitamin C and / or E on exercise performance and redox homeostasis, a permanent supplemental doses of vitamin C and / or E cannot be recommended for physically active [28].

Although studies demonstrate the effectiveness of antioxidants to alleviate the oxidative stress associated with exercise, much remains to be clarified. As such, the addition of high doses of vitamin C is not recommended to endurance athletes undergoing exercise, however adequate dietary intake of vitamin is necessary for normal muscle function [2]. Vitamin C may have little or no effect of supplementation; however, the reduction of their body stores may contribute to increased oxidative stress [1].

Why is there so much disagreement among studies on the effect of vitamin C on exercise adaptations? It is believed that the main reason is the very uniqueness of each study in terms of the type of exercise (aerobic or anaerobic), species (rat or human), age (young or old), tissue (blood or muscle), oxidative biomarker and training of endpoints examined. Other factors that could explain the diversity of results include nutrition, subject, exercise and characteristics of experimental error arising from the complexity of the techniques used in the analysis. Finally, the lack of consensus may be partially explained by the biological variability [28].

Based on the conflicting evidence on the effects of increased intake of vitamin C on exercise performance and homeostasis, a permanent entry of non-physiological doses of vitamin C should not be recommended for healthy individuals. This should not be confused with a high intake of fruits and vegetables, which is safe and beneficial [28].

Thus, we see the importance of proper and regular intake of vitamin C in the diet, but more research is needed to clarify whether supplementation of this nutrient actually carries on optimizing performance.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments/Grant Support

This study was supported by Universidade Federal do Rio Grande do Sul (UFRGS) and Universidade Federal do Sergipe (UFS).

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