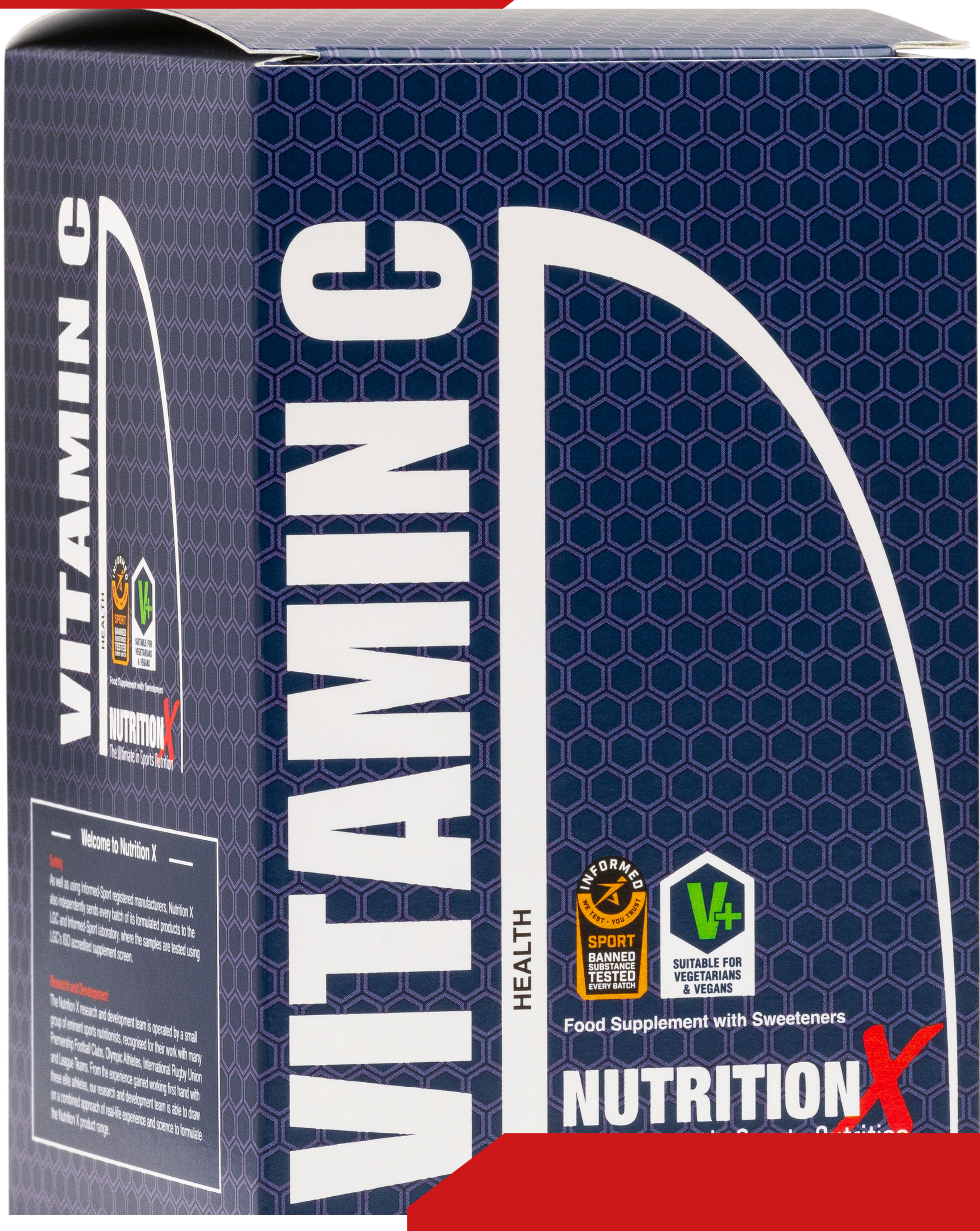
THE SCIENCE BEHIND



VITAMIN C

Vitamin C, Health & Performance

Key points

- Vitamin C is a water-soluble vitamin and hence needs to be taken in regularly as it is not stored (at least not for long)
- It is an essential nutrient, which in cases of deficiency can lead to a number of health issues including death
- The daily dose of vitamin C for adults is 40-60mg/day, but this level needs to be increased by athletes to around 100-1000mg/day depending on the severity of training
- The daily dose maybe increased during winter periods when there are increase chances of colds, flu and so on
- Vitamin C is an antioxidant and hence has health benefits
- Vitamin C is important in both wound healing and collagen formation which is of benefit to athletes engaged in sports where damage to skin, ligaments and tendons is likely
- Vitamin C has an important role in immune function which is important for a healthy athlete – notably in winter months when colds and flu are endemic

Introduction

Vitamin C (also known as ascorbic acid or ascorbate) is a vitamin found in various foods and sold as a dietary supplement. It is used to prevent and treat scurvy, and is an essential nutrient involved in the repair of tissue, the enzymatic production of certain neurotransmitters, the functioning of several enzymes and is important for immune system function. It also functions as an antioxidant. Most animals and plants are able to synthesize their own vitamin C, although humans, apes, and certain other animals cannot do so and must acquire it from dietary sources. There is some evidence that regular use of vitamin C supplements may reduce the duration of the common cold, although it does not appear to prevent infection. It is unclear whether supplementation affects the risk of cancer, cardiovascular disease, or dementia although there is ongoing research in these fields. Vitamin C is generally well tolerated. Large doses may cause gastrointestinal discomfort, headache, trouble sleeping, and flushing of the skin.

Vitamin C functions as a cofactor in many enzymatic reactions that mediate a variety of essential biological functions, including wound healing and collagen synthesis. In humans, vitamin C deficiency leads to impaired collagen synthesis, contributing to the more severe symptoms of scurvy. Another biochemical role of vitamin C is to act as an antioxidant. Vitamin C is also a cofactor for the hydroxylase enzymes involved in the synthesis of catecholamine hormones, e.g., adrenalin and noradrenalin, and amidated peptide hormones e.g., vasopressin, which are central to the cardiovascular response to severe infection. Furthermore, research over the past 15 years or so has uncovered new roles for vitamin C in the regulation of gene transcription and cell signaling pathways through regulation of transcription factor activity and epigenetic marks (Figure 1). Recent research has also indicated an important role for vitamin C in regulation of DNA and histone methylation.

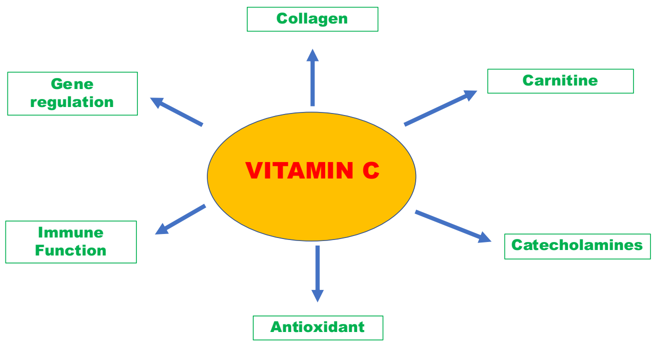


Figure 1. Some likely functions of Vitamin C.

History

Through history the need for people to eat fresh plant food to help them get through long sieges or long sea trips was well recognized but not often mentioned. Scurvy had long been a principal killer of sailors during the long sea voyages. In 1499, Vasco da Gama lost 116 of his crew of 170, and in 1520, Magellan lost 208 out of 230, all mainly to scurvy. James Lind, a British Royal Navy surgeon identified in 1747 that a quality in fruit prevented scurvy in one of the first recorded controlled experiments. While at sea in 1747, Lind provided some crew members with two oranges and one lemon per day in addition to normal rations, while others continued on cider, vinegar, or seawater, along with their normal rations, in one of the world's first controlled experiments. The results showed that citrus fruits prevented the disease. Lind published his work in 1753 in his Treatise on the Scurvy.

Fresh fruit was expensive to keep on board, whereas boiling it down to juice allowed easy storage but destroyed the vitamin (especially if boiled in copper kettles). It was 1796 before the British navy adopted lemon juice as standard issue at sea. In 1845, ships in the West Indies were provided with lime juice instead, and in 1860 lime juice was used throughout the Royal Navy, giving rise to the American use of the nickname "limey" for the British. Captain James Cook had previously demonstrated the advantages of carrying "Sour krout" on board, by taking his crews to the Hawaiian Islands without losing any of his men to scurvy. For this, the British Admiralty awarded him a medal.

In 1912 the Polish American scientist Casimir Funk first used the word vitamin for something present in food in small amounts that is essential to health. He named the unknown thing that prevented scurvy, Vitamin C. From 1928 to 1933, the Hungarian research team of Joseph Svirbely and Albert Szent-Gyorgyi, and separately the American Charles King, first extracted vitamin C from food and showed it to be an acid they called ascorbic acid. In 1933/1934, the British chemists Norman Haworth and Edmund Hirst successfully synthesized the vitamin. It was the first man-made vitamin, and thus made it possible to make vitamin C cheaply in factories. Haworth won the 1937 Nobel Prize for Chemistry for this work whilst Szent-Gyorgyi won the Nobel prize in Medicine. In 1959 the American J.J. Burns showed that the reason why some animals get scurvy is because their liver cannot make one chemical enzyme that other animals have.

Notable human dietary studies of experimentally induced scurvy were conducted on conscientious objectors during World War II in Britain and also on Iowa state prisoners in the late 1960s to the 1980s. Men in the prison study developed the first signs of scurvy around four weeks after starting the vitamin C-free diet, whereas in the earlier British study, six to eight months were required, possibly due to the pre-loading of this group with a 70 mg/day supplement for six weeks before the experimental diet began. Men in both studies had blood levels of ascorbic acid too low to be accurately measured by the time they developed signs of scurvy. These studies both reported that all obvious symptoms of scurvy could be completely reversed by supplementation of 10 mg a day

Although the amount of vitamin C required to prevent scurvy is relatively low (i.e., ~10 mg/day), the recommended dietary intakes for vitamin C are up to one hundred-fold higher than that for many other vitamins. A diet that supplies 100–500 mg/day of vitamin C provides adequate plasma concentrations in healthy individuals and should cover general requirements for the reduction of chronic disease risk. Due to the low storage capacity of the body for the water-soluble vitamin, a regular and adequate intake is required to prevent hypovitaminosis C. Epidemiological studies have indicated that hypovitaminosis C (plasma vitamin C < 23 µmol/L) is relatively common in Western populations, and vitamin C deficiency (<11 µmol/L) is common in many western countries. There are several reasons why vitamin C dietary recommendations are not met, even in countries where food availability and supply would be expected to be sufficient. These include poor dietary habits, life-stages and/or lifestyles either limiting intakes or increasing micronutrient requirements (e.g., smoking and alcohol or drug abuse), various diseases, exposure to pollutants and smoke (both active and passive), and economic reasons (poor socioeconomic status and limited access to nutritious food). Even otherwise ‘healthy’ individuals in industrialized countries can be at risk due to lifestyle-related factors, such as those on a diet or eating an unbalanced diet, and people facing periods of excessive physical or psychological stress such as athletes (notably during strenuous training periods and competition.

Vitamin C and athletes

Micronutrients play an important role in energy production, haemoglobin synthesis, maintenance of bone health, adequate immune function, and protection of body against oxidative damage. They assist with synthesis and repair of muscle tissue during recovery from exercise and injury. Exercise stresses many of the metabolic pathways where micronutrients are required, and exercise training may result in muscle biochemical adaptations that increase micronutrient needs. Routine exercise may also increase the turnover and loss of these micronutrients from the body. As a result, greater intakes of micronutrients may be required to cover increased needs for building, repair, and maintenance of lean body mass in athletes. The most common vitamins and minerals found to be of concern in athletes' diets are calcium and vitamin D, the B vitamins, iron, zinc, magnesium, as well as some antioxidants such as vitamins C and E, A-carotene, and selenium (Lukaski, 2004). Athletes at greatest risk for poor micronutrient status are those who restrict energy intake or have severe weight-loss practices, who eliminate one or more of the food groups from their diet, or who consume unbalanced and low micronutrient-dense diets. These athletes may benefit from a daily multivitamin-and-mineral supplement. Use of vitamin and mineral supplements does not improve performance in individuals consuming nutritionally adequate diets (Position statement ACSM, 2009).

The antioxidant nutrients, vitamins C and E, A-carotene, and selenium, play important roles in protecting cell membranes from oxidative damage. Because exercise can increase oxygen consumption by 10-15 fold, it has been hypothesized that long-term exercise produces a constant ‘‘oxidative stress’’ on the muscles and other cells leading to lipid peroxidation of membranes. Although short-term exercise may increase levels of lipid peroxide by-products, habitual exercise has been shown to result in an augmented antioxidant system and reduced lipid peroxidation. Thus, a well-trained athlete may have a more developed endogenous antioxidant system than a sedentary person. Whether exercise increases the need for antioxidant nutrients remains controversial. There is little evidence that antioxidant supplements enhance actual physical performance (Gleeson et al., 2004; Mastaloudis et al., 2006). Athletes at greatest risk for poor antioxidant intakes are those following a low-fat diet, restricting energy intakes, or limiting dietary intakes of fruits, vegetables, and whole grains.

Vitamin C supplements do not seem to have an ergogenic effect if the diet provides adequate amounts of this nutrient, but because strenuous and prolonged exercise has been shown to increase the need for vitamin C, physical performance can be compromised with marginal vitamin C status or deficiency. Athletes who participate in habitual prolonged, strenuous exercise are recommended to consume 100–1000 mg of vitamin C daily (Keith, 2006; Lukaski, 2004).

To date there is no evidence that supplementing with vitamin C for athletes who have an adequate intake will enhance performance. However, the benefits for athletes are based on maintaining good health, having a robust immune function, enhancing wound and skin healing, and providing antioxidant support.

Vitamin C in foods

Foods containing vitamin C include citrus fruits, kiwifruit, guava, broccoli, brussels sprouts, bell peppers and strawberries (see Table 1), whereas there is almost no vitamin C in animal products (see Table 2). Prolonged storage or cooking may reduce vitamin C content in foods.

Table 1. Relative amount (mg/100g) of Vitamin C in some Fruits and Raw Vegetables

Fruit/Veg	mg/100g	Fruit/Veg	mg/100g	Fruit/Veg	mg/100g
Rose hip	2000	Tangerine/ Mandarin oranges	30	Crab apple	8
Blackcurrant	200	Passion fruit	30	Peach	7
Gooseberry	445	Spinach	30	Apple	6
Guava	100	Cabbage	30	Blackberry	6
Kiwifruit	90	Lime	20	Beetroot	5
Broccoli	90	Mango	20	Pear	4
Loganberry	80	Melon, honeydew	20	Lettuce	4
Redcurrant	80	Raspberry	20	Cucumber	3
Brussels sprouts	80	Tomato	10	Fig	2
Lychee	70	Blueberry	10	Bilberry	1
Papaya	60	Pineapple	10		
Strawberry	50	Grape	10		
Lemon	40	Apricot	10		
Melon, cantaloupe	40	Plum	10		
Cauliflower	40	Watermelon	10		
Grapefruit	30	Carrot	9		
Raspberry	30	Avocado	8		
Orange	50	Banana	9		

Table 2. Relative amount (mg/100g) of Vitamin C in Foods of Animal Origin

Food of animal origin	mg/100g	Food of animal origin	mg/100g
Calf liver (raw)	36	Cow's milk (fresh)	2
Beef liver (raw)	31	Goat's milk (fresh)	2
Oysters (raw)	30	Beef steak (fried)	0
Cod Roe (fried)	26	Hen's egg (raw)	0
Pork liver (raw)	23	Pork Bacon (fried)	0
Chicken liver (fried)	13	Calf veal cutlet (fried)	0
Lamb liver (Fried)	12	Chicken leg (roast)	0
Lamb heart (roast)	11		

Vitamin C and Immune Function

Vitamin C has a number of activities that could conceivably contribute to its immune-modulating effects. It is a highly effective antioxidant, thus protecting important biomolecules (proteins, lipids, carbohydrates, and nucleic acids) from damage by oxidants generated during normal cell metabolism (increased by exercise) and through exposure to toxins and pollutants (e.g., cigarette smoke). Vitamin C is also a cofactor for a family of biosynthetic and gene regulatory enzymes. The vitamin has long been known as a cofactor for the lysyl and prolyl hydroxylases required for stabilization of the structure of collagen (see Science of Repair shot), and is a cofactor for the certain enzymes involved in carnitine biosynthesis, a molecule required for transport of fatty acids into mitochondria for generation of metabolic energy.

Overall, vitamin C appears to exert a multitude of beneficial effects on cellular functions of both the innate and adaptive immune system. Although vitamin C is a potent antioxidant protecting the body against endogenous and exogenous oxidative challenges, it is likely that its action as a cofactor for numerous biosynthetic and gene regulatory enzymes plays a key role in its immune-modulating effects. Vitamin C stimulates neutrophil migration to the site of infection, enhances phagocytosis and oxidant generation, and microbial killing. At the same time, it protects host tissue from excessive damage by enhancing neutrophil apoptosis and clearance by macrophages, and decreasing neutrophil necrosis. Thus, it is apparent that vitamin C is necessary for the immune system to mount and sustain an adequate response against pathogens, whilst avoiding excessive damage to the host.

Vitamin C appears to be able to both prevent and treat respiratory and systemic infections by enhancing various immune cell functions. Prophylactic prevention of infection requires dietary vitamin C intakes that provide at least adequate, if not saturating plasma levels (i.e., 100–200 mg/day), which optimize cell and tissue levels. In contrast, treatment of established infections requires significantly higher (gram) doses of the vitamin to compensate for the increased metabolic demand.

Epidemiological studies indicate that hypovitaminosis C is still relatively common in Western populations, and vitamin C deficiency is the fourth leading nutrient deficiency in the United States. Reasons include reduced intake combined with limited body stores. Increased needs occur due to pollution and smoking, fighting infections, and diseases with oxidative and inflammatory components, e.g., type 2 diabetes, etc. Ensuring adequate intake of vitamin C through the diet or via supplementation, especially in groups such as the elderly or in individuals exposed to risk factors for vitamin C insufficiency, is required for proper immune function and resistance to infections. For a greater in depth understanding it is advisable to read Carr & Maggini (2017).

Vitamin C and Tissue Healing

It is well understood that wound healing requires synthesis and accumulation of collagen and subsequent cross-linking of the fibre to give new tensile strength to the damaged tissue. An early study demonstrated that maximum tensile strength of scar tissue was achieved after supplementation of vitamin C. Since then, various studies have been carried out to evaluate the role of vitamin C in wound repair and healing/regeneration process as it stimulates collagen synthesis. Adequate supplies of vitamin C are necessary for normal healing process especially for post-operative patients because there is rapid utilization of vitamin C for the synthesis of collagen at the site of wound/ burns during post-operative period hence, administration of 500 mg to 1.0 g/day of vitamin C are recommended to accelerate the healing process (Chambial et al., 2013). See appropriate section in 'Science of Repair shots' for a little more detail.

Vitamin C and Iron

Vitamin C is known to enhance the availability and absorption of iron from non-haem iron sources. Supplementation is found to facilitate the dietary absorption of iron. The reduction of iron by vitamin C has been suggested to increase dietary absorption of non-haem iron. Vitamin C rich fruits such as goose berry has been reported to increase the bioavailability of iron from staple cereals and pulses. Accumulating evidence strongly suggests that in addition to the known ability of dietary vitamin C to enhance non-haem iron absorption in the gut, vitamin C can regulate cellular iron uptake and metabolism. Vitamin C modulates iron metabolism by stimulating ferritin synthesis, inhibiting lysosomal ferritin breakdown, and decreasing cellular iron efflux. This is a vast topic and can be quite complex, so if you wish to gain an in-depth understanding, please read Lane & Richardson (2014). Suffice to say that female athletes during menstruation (particularly if blood loss is high) would be advised to consume iron supplements with vitamin C (fruits or fruit juices or supplements). Furthermore, vegetarian and vegan athletes are unlikely to gain sufficient iron from their diet may consider iron and vitamin C supplementation.

Conclusion

From a sports perspective an overall finding by Braakhuis (2012) following examination of a number of studies on vitamin C and performance concluded the following:

"Antioxidant supplements are widely used by athletes to avoid elevated oxidative stress, the consequences of which include muscle damage, immune dysfunction, and fatigue. It appears to be an erroneous assumption to provide athletes with ***megadoses*** *of antioxidant supplements to avoid oxidative stress and subsequently performance.*

Vitamin C decreases oxidative stress taken in doses of 200-1000mg/day. However, in larger doses (>1000mg/day) Vitamin C appears to reduce training-induced adaptations by reducing mitochondrial biogenesis or by possibly altering vascular function. A smaller dose of vitamin C (200mg/day), provided by five servings of fruit and vegetables daily, may be sufficient to reduce oxidative stress but not past a threshold that will impair optimal training adaptations. Short-term intakes (1 to 2 wk) of >200mg/day may benefit athletes during times of increased stress. Further research is required to clarify a dose-response and nutrient timing protocols on vitamin C"

Vitamin C is an essential nutrient required to be consumed regularly for health benefits (and for life!). Athletes have a greater requirement for vitamin C than sedentary individuals and should consider consuming 200-1000mg/day, with the higher dose during more stressful training and competitive periods. Furthermore, for those who are injured or undergoing surgery, vitamin C may prove helpful for wound healing.

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