Section Two

Vitamins
2 Ascorbic Acid

Robert E. Keith

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I. INTRODUCTION

The relationship between ascorbic acid and exercise has been studied for a number of years, with several review articles having been written covering this topic.\textsuperscript{1-5} This chapter will further address the knowledge base concerning vitamin C and exercise. Such topics as the basic functions and deficiency symptoms of ascorbic acid as related to exercise will be covered. In addition, articles related to exercise and vitamin C requirements; immune function; cortisol secretion and stress; muscle soreness; supplementation and sports performance and intakes/needs of physically active persons for the vitamin will be reviewed.

A. HISTORY

While the existence of vitamin C has been known for only a relatively short time, the fact that a vitamin C deficiency could adversely affect physical performance has been documented for centuries.\textsuperscript{1,4} There are reports from the British Navy of the late 1700s concerning sailors with scurvy (vitamin C deficiency).\textsuperscript{4} These reports describe sailors who had good appetites and were cheerful, yet collapsed and died on deck upon the initiation of physical activity. During the Crimean War (1854–6) and the American Civil War, scurvy was reported among the soldiers. Those having scurvy were reported to have shortness of breath upon exertion and greatly reduced energy and powers of endurance.\textsuperscript{4} These are just a couple of examples of how ascorbic acid deficiency has adversely affected the physical ability of sailors and soldiers in the last several centuries, and other stories of scurvy’s effects on physical performance exist.\textsuperscript{4} Thus, while the study of vitamin C and physical performance is a relatively new area, the fact that scurvy has caused decreases in physical performance has existed for centuries.
B. **General Properties and Structure**

Vitamin C is a water-soluble vitamin for humans, primates and guinea pigs. Most other animal species can make ascorbic acid from the sugar glucose, but humans lack an enzyme necessary to convert glucose to ascorbic acid. Vitamin C exists in humans in two biologically active forms, ascorbic acid and dehydroascorbic acid. It is the ability to interconvert between these two forms that gives vitamin C antioxidant capabilities.6–10

Dietary intakes of vitamin C are absorbed in the upper small intestines by active transport mechanisms at physiological intakes (50–200 mg/day). Large intakes (gram doses) of the vitamin may be absorbed by passive diffusion. Most (80–90%) of a physiological dose will be absorbed. However, this absorbance value may drop to 10–20% for megadoses. Vitamin C is found in high concentrations in the adrenal glands, pituitary gland, white blood cells, the lens of the eye and brain tissue.6–10

C. **Functions**

Ascorbic acid has several important functions as related to physical activity. The vitamin has long been known to be necessary for normal collagen synthesis. Collagen, one of the most abundant proteins in the body, is a vital component of cartilage, ligaments, tendons and other connective tissue. Vitamin C is needed for the formation of the vitamin-like compound carnitine, which is necessary for the transport of long-chain fatty acids into the mitochondria. The fatty acids can then be used as an energy source. The neurotransmitters, norepinephrine and epinephrine also require vitamin C for their synthesis. Ascorbic acid seems to be needed for the proper transport of nonheme iron, the reduction of folic acid intermediates and for the proper metabolism of the stress hormone cortisol. Finally, vitamin C acts as a powerful water-soluble antioxidant. The vitamin seems to exert antioxidant functions in plasma and probably interfaces at the lipid membrane level with vitamin E to regenerate vitamin E from the vitamin E radical. Table 2.1 describes some of these functions in more detail.6–10

Through these various functions vitamin C can interface with physical activity at several levels. For example, poor development of connective tissue could result in increased numbers of ligament and tendon injuries and poor healing of these injuries. Inadequate production of carnitine would decrease a person’s ability to utilize fatty acids as an energy source. This would force increased use on glycogen stores, exhausting these stores earlier during exercise and causing fatigue and decreased performance. With decreased production of norepinephrine and epinephrine, an athlete might not be able to properly stimulate the neural and metabolic systems necessary for optimal performance. Poor iron and folate metabolism would result in anemia’s impairing the transport of oxygen to tissues. This would be a

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**TABLE 2.1**

Selected Functions of Vitamin C That Would Affect Physical Performance

<table>
<thead>
<tr>
<th>Chemical Reaction Requiring Vitamin C</th>
<th>Body Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) lysine → hydroxylysine</td>
<td>Needed for normal collagen (cartilage, connective tissue, ligaments, tendons)</td>
</tr>
<tr>
<td>proline → hydroxyproline</td>
<td></td>
</tr>
<tr>
<td>2) lysine → carnitine</td>
<td>Necessary for normal fat oxidation in muscle cell mitochondria</td>
</tr>
<tr>
<td>(liver, kidney)</td>
<td></td>
</tr>
<tr>
<td>3) phenylalanine → dopamine, norepinephrine, epinephrine</td>
<td>Needed for normal neurotransmitter formation</td>
</tr>
<tr>
<td>4) ascorbic acid ↔ dehydroascorbic acid</td>
<td>Normal antioxidant function</td>
</tr>
</tbody>
</table>

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definite hindrance to optimal performance in aerobic endeavors. Through its various functions, vitamin C has ample opportunity to interface with physical performance at several metabolic sites.

D. DEFICIENCY AND PHYSICAL PERFORMANCE

It should be apparent from the previous section that a vitamin C deficiency (scurvy) would cause a decrease in physical performance. This point is not controversial. Table 2.2 lists the major symptoms of vitamin C deficiency and how each symptom could decrease a certain aspect of physical activity.

Marginal status for ascorbic acid probably also exerts some detrimental effects on performance. For example, Lemmel studied 110 children receiving a diet low in ascorbic acid. The addition of 100 mg daily of ascorbic acid over a 4-month period improved the work capacity and liveliness of 48% of the children as compared with 12% in a control group. Babadzanjan et al. studied 40 train engine drivers and crew. These individuals initially had low vitamin C status. The administration of 200 mg of vitamin C per day normalized blood concentrations and reduced fatigue in these subjects. Buzina and Suboticanec reported that VO\textsubscript{2}max values were improved in young adolescents having low plasma concentrations of vitamin C when these adolescents were supplemented with vitamin C. The improvement in the VO\textsubscript{2}max stopped when plasma C concentrations were normalized. Van der Beek et al. produced marginal vitamin C status in subjects by feeding them 32.5–50% of the Dutch RDA for vitamin C for 3 to 8 weeks. In one study, an increased heart rate was seen at the “onset of blood lactate” level during the time of reduced vitamin C intake. In addition, reduced vitamin C status may have been partly responsible for a significant reduction in aerobic power seen in the other study. More recently, Johnston et al. studied the effects of vitamin C supplementation on nine vitamin C-depleted male and female subjects who were apparently healthy and unaware of their low serum vitamin C concentrations. The subjects were given 500 mg of vitamin C a day for 2 weeks. Compared with pre-supplementation values, work performed by the subjects on a graded walking protocol and gross work efficiency increased significantly by 10 and 15%, respectively.

E. RECOMMENDED INTAKES AND FOOD SOURCES

The current adult Dietary Reference Intake/Recommended Dietary Allowance (RDA) for vitamin C is 75 mg/day for women and 90 mg/day for men. This level of intake is known to maintain adequate tissue levels of the vitamin and prevent signs of scurvy in most individuals. However, these guidelines were developed for light to moderately active people, not specifically for athletes or persons engaged in strenuous or prolonged physical activity.
Various forms of physiological stress are known to increase the need for vitamin C. These include infections, cigarette smoking, extreme environmental temperature and altitude, among others. Strenuous or prolonged exercise is a form of physiological stress and could possibly increase requirements and, thus, recommended intakes of the vitamin in physically active individuals. This point will be further explored later in this chapter. However, to date, no official recommendations for vitamin C intake for physically active individuals have been made.

Vitamin C is found naturally, and almost exclusively, in fruits and vegetables. Some vitamin C can be found in milk and liver, but these values are minimal. In addition to natural sources of the vitamin, many foods such as breakfast cereals, some sports drinks and various nutrition bars, for example, are now fortified with the vitamin. Thus, it is more likely today than ever before that significant vitamin C intake could be obtained from foods other than fruits and vegetables. Nonetheless, vitamin C can be different in terms of intake as compared with many other vitamins, particularly the B complex vitamins. B complex vitamin intake tends to correlate well with total energy intake of an athlete. Thus, if athletes are consuming sufficient energy, it is reasonably likely that their dietary intake for B complex vitamins such as thiamin and niacin is also sufficient. However, because ascorbic acid is found principally in some fruits and vegetables, the possibility exists that athletes could have an otherwise adequate diet but one that is low in vitamin C. This would occur if the athletes did not consume sufficient servings of fruits and vegetables or other vitamin C fortified foods. The vitamin C content of selected fruits and vegetables can be found in Table 2.3.

### II. EXERCISE AND ASCORBIC ACID REQUIREMENTS

One question that researchers have asked is, “What effects does the stress of physical activity have on the requirements for vitamin C?” A possible answer to this question can be evaluated by looking at direct changes in tissue concentrations of blood/plasma, white blood cells and urine. Indirect answers to this question can be obtained by looking in areas such as heat acclimation, muscle soreness or damage, respiratory infection rates and the levels of the stress hormone, cortisol.

#### A. DIRECT EFFECTS: BODY TISSUES, BLOOD/PLASMA, WHITE BLOOD CELLS, URINE

Several animal studies have been performed that addressed the exercise/vitamin C requirement question. These studies are in general agreement that exercise reduces the vitamin C content of
various tissues such as the adrenal glands, spleen, liver and brain. This would seem to indicate that exercise increased the need for vitamin C in these animals.

Studies evaluating the effect of exercise on ascorbic acid needs in humans are greater in number and more diverse in their approach as compared with animal studies. Human studies have addressed the relationship between exercise and vitamin C for blood/plasma and leukocyte concentrations of the vitamin, excretion in the urine, immune function, hormonal status, muscle soreness or damage and heat stress adaptation.

Several papers have evaluated blood/plasma vitamin C changes with exercise or in athletes at rest. Namyslowski and Desperak-Secomska\textsuperscript{28} found decreased blood vitamin C levels in a group of physical culture students. Although the diets of the students might not have been adequate in vitamin C, the authors concluded that strenuous exercise had caused an additional decrease in these blood concentrations. Namyslowski\textsuperscript{29} followed the first research project with a second study. This study found that blood vitamin C levels decreased in athletes ingesting 100 mg of vitamin C/day. Dietary intakes of 300 mg/day were required to maintain or increase blood concentrations of ascorbic acid in the athletes. Recently, Schroder et al.\textsuperscript{30} reported that the plasma vitamin C concentrations of a group of professional basketball players decreased significantly over a 32-day competitive season, with the final plasma value (15.4 µmol/L) falling below the minimum acceptable concentration.

However, several other studies\textsuperscript{31–39} have reported normal mean vitamin C concentrations in the plasma of athletes and physically active individuals; although at least one study\textsuperscript{37} reported 12% of its subjects with low plasma vitamin C concentrations, while another\textsuperscript{33} had mean ascorbic acid concentrations for its subjects at the low end of normal range. Plasma vitamin C concentrations above 23 µmol/L are often considered adequate.\textsuperscript{5,40} Mean plasma vitamin C concentrations in active, mostly male subjects have been reported to range from a low of 35 to a high of 86 µmol/L. One study with female ballet dancers reported a plasma vitamin C concentration of 46 µmol/L.\textsuperscript{34} Thus, for the most part, resting plasma concentrations in physically active individuals appear to be normal. However, some care must be taken in interpreting these values as compared with a sedentary population. Several papers have reported that recent physical activity can increase plasma vitamin C concentrations for up to 24 hours.\textsuperscript{31–33,41} Thus, plasma values for vitamin C in some of the reported studies could possibly be falsely elevated if they were obtained within 24 hours of strenuous exercise. This could be a mitigating factor in evaluating plasma vitamin C in athletes. Furthermore, plasma vitamin C values have been recorded mostly in runners. Data are not available for plasma vitamin C concentrations in other groups such as weightlifters, swimmers and cyclists. Plasma vitamin C values in various athletic groups can be seen in Table 2.4.

<table>
<thead>
<tr>
<th>Athletic group</th>
<th>No. of Subjects</th>
<th>Ascorbic Acid Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Various athletes</td>
<td>50 M, 36 F</td>
<td>56</td>
<td>37</td>
</tr>
<tr>
<td>Runners</td>
<td>4 M</td>
<td>79</td>
<td>31</td>
</tr>
<tr>
<td>Runners</td>
<td>7 M</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>Runners</td>
<td>9 M</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>Runners</td>
<td>30 M</td>
<td>58</td>
<td>35</td>
</tr>
<tr>
<td>Various athletes</td>
<td>55 M</td>
<td>74</td>
<td>36</td>
</tr>
<tr>
<td>Ballet dancers</td>
<td>10 M, 12 F</td>
<td>59 M, 46 F</td>
<td>34</td>
</tr>
<tr>
<td>Trained runners</td>
<td>6 M, 6 F</td>
<td>72</td>
<td>38</td>
</tr>
<tr>
<td>Ultramarathoners</td>
<td>15 M</td>
<td>83</td>
<td>39</td>
</tr>
</tbody>
</table>

Normal plasma ascorbic acid concentration range = 23–114.0 µmol/L.\textsuperscript{5,40}
Several studies have examined the relationship between white blood cell/leukocyte ascorbic acid concentrations and exercise. One study evaluated changes in white blood cell ascorbic acid concentrations in 31 professional soccer players before and after a strenuous 2-hour training session. The white blood cell ascorbic acid content decreased following the training session. The authors likened this fall with the fall in white blood cell vitamin C seen following other stressful events such as myocardial infarction and the common cold. Ferrandez et al. reported on the leukocyte ascorbic acid concentrations in a group of Olympic cyclists in the third year of their 4-year training program. These authors reported that lymphocyte and neutrophil vitamin C concentrations declined significantly over the length of the study. In addition, the authors further reported that lymphocyte and neutrophil ascorbic acid levels declined from a pre-Olympic to a post-Olympic games test. However, two other studies do not support an increased vitamin C requirement in athletes based on leukocyte evidence. Robertson et al. reported on the lymphocyte ascorbic acid concentrations in a group of six highly trained runners compared with an equal number of sedentary control subjects. The runners had significantly greater lymphocyte ascorbic acid levels. Krause et al. measured neutrophil function in two groups of biathletes following a strenuous competition. One group received vitamin C at 2 grams per day for a week while the other group received a placebo. Neutrophil function decreased following the competition in both groups with no significant differences between the groups.

Two studies have reported decreased urinary excretion of vitamin C with increased physical activity. Bacinskij studied 30 young sedentary male medical students and 33 physical-culture students who participated in various forms of exercise on a daily basis. The physical-culture students excreted only about 50% of the vitamin C excreted by the medical students. The author concluded that persons engaged in physical activity need extra vitamin C. Namyslowski also reported decreased urine vitamin C in a group of skiers. The author suggested that the skiers needed 200–250 mg of vitamin C each day. However, two other studies reported no significant differences in urine excretion of vitamin C between runners and male athletes and their sedentary controls.

B. INDIRECT EFFECTS: HEAT ACCLIMATION, MUSCLE SORENESS/DAMAGE, RESPIRATORY INFECTIONS, CORTISOL

Several papers have examined the relationships among exercise, vitamin C needs and adaptation to heat stress in humans. An early study found no effect of 500 mg of vitamin C on rectal temperature, sweat rate, recovery heart rate or strength in subjects working in a hot environment. However, studies since then have found some improvement in the ability of humans to exercise in a hot environment when they were given additional vitamin C.

Strydom et al. studied the effects of vitamin C ingestion (250 or 500 mg/day for 21 days vs. placebo) in a group of 60 mining recruits undergoing climatic room acclimatization. Subjects were not exposed to heat for at least 6 months prior to the study. Exercise consisted of a 4-hour step test in a comfortable environment (20–22°C) versus repeated testing in a hot environment (32.2°C wet bulb and 33.9°C dry bulb). Results indicated no differences among groups for heart rate or total sweat rate. However, rectal temperatures were significantly lower in the groups receiving vitamin C. The authors concluded that the rate and degree of heat acclimatization was enhanced by vitamin C supplementation.

Kotze et al. also investigated heat acclimation in 13 male volunteers. Subjects exercised 4 hours each day for 10 days in a manner and under conditions previously described by Strydom et al. Volunteers were placed into diet groups receiving 250 or 500 mg vitamin C daily or a placebo. Groups receiving vitamin C had a reduction in total sweat output and rectal temperature. The authors concluded that vitamin C may be effective in reducing heat strain in unacclimatized persons.

Four papers outlined below have reported on vitamin C and muscle soreness or damage. Two of the papers reported that vitamin C had no effects on muscle soreness. However, two other studies did find that vitamin C supplementation above RDA levels improved muscle soreness or damage markers.
An early study by Staton\textsuperscript{53} showed no differences in delayed muscle soreness as measured after a sit-up test between subjects receiving 100 mg of vitamin C and those receiving a placebo. Thompson et al.\textsuperscript{54} gave 1,000 mg of ascorbic acid 2 hours prior to exercise to nine active males. These same subjects also received a placebo treatment on another trial. Subjects underwent a 90-minute shuttle running test that mimicked multiple sprints. Measurements were taken for muscle damage (creatine kinase) and lipid peroxidation (malondialdehyde) as well as muscle soreness. No differences were noted between treatment and placebo trials. The authors concluded that acute supplementation of vitamin C had no beneficial effects on muscle soreness. However, the authors stated that short-term ascorbic acid supplementation might have been ineffective because the timing of the supplement was incorrect. However, in a study by Jakeman and Maxwell\textsuperscript{55} post-exercise maximal voluntary isometric contraction of an eccentrically exercised leg was determined over a 7-day period of time. In general, retention of force production was better in a group of subjects receiving 400 mg of vitamin C a day for 21 days prior to exercise as compared with a group receiving vitamin E. The authors concluded that vitamin C may offer some protection from eccentric exercise-induced muscle damage.

In a second study, Thompson et al.\textsuperscript{56} measured muscle soreness and muscle function in 16 (eight vitamin C, eight placebo) regularly training male subjects. The vitamin C group received 400 mg of the vitamin a day for 2 weeks prior to testing. Subjects undertook a 90-minute strenuous intermittent shuttle run. Muscle soreness was assessed using a 10-point scale and muscle function was assessed on the flexors and extensors of both legs using an isokinetic dynamometer. Vitamin C had beneficial effects on muscle soreness and muscle function. In addition, plasma malondialdehyde and interleukin-6 concentrations were lower at certain post-exercise time periods in the vitamin C group.

Research has previously documented that strenuous or prolonged exercise can compromise the immune system.\textsuperscript{38,57} This compromised immune system may then allow for an increased incidence of infections, particularly upper respiratory tract infections (URTI), in athletes. Several studies\textsuperscript{58–61} have investigated the relationship between ascorbic acid and URTI.

Peters et al.\textsuperscript{58} evaluated the effects of a vitamin C supplement (600 mg/day for 21 days or a placebo) on the incidence of URTI in a group of ultramarathoners following a race. Runners were monitored for 14 days following the race. A total of 68% of the runners in the placebo group had symptoms of URTI following the race. Only 33% of the vitamin C-supplemented subjects had symptoms. This difference was significant. Peters et al.\textsuperscript{59} followed up their initial research with another study involving ultramarathoners, vitamin C and URTI. Results were similar to the first study. Runners received either 500 mg of vitamin C a day or a placebo for 21 days prior to a 90-kilometer race. URTI was monitored for 14 days post-race. URTI occurred in 16% of the vitamin C runners and 40% of the placebo runners. Again, this difference was significant. Peters et al.\textsuperscript{58} concluded that vitamin C supplementation may enhance resistance to post-race URTI. Other studies\textsuperscript{60} have looked at vitamin C supplementation and URTI in school children undergoing training at a ski camp and military troops undergoing strenuous training. Vitamin C was given at levels of 600–1000 mg/day and placebo groups were included. Vitamin C supplementation reduced URTI symptoms in these studies approximately 50%. In contrast to the four previous studies, Himmelstein et al.\textsuperscript{61} did not find a significant difference in URTI between vitamin C-treated and placebo marathon runners. In this study,\textsuperscript{51} 44 marathon runners were given either 1,000 mg of vitamin C a day or a placebo for 2 months prior to their marathon. They were then followed for 1 month post-marathon. URTI incidence in the vitamin C runners was 33% and for the placebo runners 43%.

The secretion of the hormone cortisol also has been studied in relation to exercise and vitamin C. Cortisol is released from the adrenal gland in response to physiological and psychological stress.\textsuperscript{5,62} Cortisol is generally thought of as a catabolic hormone, resulting in, among other functions, a loss of lean body mass. Increased secretion of cortisol may indicate a higher level of stress on the organism. Ascorbic acid is required for the synthesis of cortisol and may have a dampening effect on plasma cortisol concentrations in response to stress. This could indicate a lower level of stress in relation to the stressor. Peake\textsuperscript{4} has reviewed the relationships between ascorbic acid and cortisol metabolism.
Five recent studies have attempted to elucidate the relationship among cortisol, exercise and ascorbic acid. Nieman et al. gave 12 experienced marathon runners either a vitamin C supplement (1000 mg/day for 8 days) or a placebo. Subjects then ran on a treadmill at 75–80% VO₂max for 2.5 hours. Five blood samples were taken before and up to 6 hours following exercise. These investigators found no significant differences in plasma cortisol concentrations between the vitamin C and placebo groups. However, mean cortisol concentrations were lower at four of the five time points in the vitamin C group. Robson et al. gave 900 mg of vitamin C a day or a placebo for 7 days to 12 endurance athletes. There were no between-group differences in post-exercise plasma cortisol concentrations following a 2-hour treadmill run at 65% VO₂max. In contrast to the findings by Robson et al. and Nieman et al., three other studies have reported decreases in plasma cortisol concentrations following exercise in vitamin C-supplemented groups. Nieman et al., in a second study, reported that supplemental vitamin C reduced post-race cortisol concentrations in a group of ultramarathoners. In addition, Peters et al. reported that supplemental vitamin C (1000–1500 mg/day) for 7 days prior to racing, on race day, and 2 days following competition significantly reduced post-race plasma cortisol concentrations compared with placebo subjects in two groups of 15–16 ultramarathoners. However, while cortisol was reduced, plasma markers of tissue inflammation were significantly elevated.

In summary, vitamin C requirements have been shown to be increased with various forms of stress such as smoking, illness and injury. It seems likely that strenuous or prolonged exercise also creates sufficient stress to increase vitamin C requirements. While not always clear, the overall data reviewed in this section would tend to indicate such. All animal studies indicated decreased tissue vitamin C levels with exercise. In humans, three papers reported decreased plasma ascorbic acid concentrations with training, two of three papers reported decreased leukocyte concentrations with training and two of four papers reported decreased urine excretion. In addition, four out of five papers reported improved heat acclimation with additional vitamin C, four out five papers reported decreased URTI incidence while two (out of four) papers reported improvement in muscle soreness markers and three (out of five) reported reduced plasma cortisol concentrations with additional vitamin C. These results, coupled with the knowledge that ascorbic acid is needed for such functions as epinephrine, carnitine and collagen synthesis as well as normal iron metabolism, would give support to the concept that strenuous or prolonged exercise and training would increase vitamin C requirements. On the other hand, it is not likely that light to moderate levels of exercise and training would significantly increase vitamin C requirements.

### III. EFFECTS OF SUPPLEMENTAL ASCORBIC ACID ON VARIOUS ASPECTS OF PHYSICAL PERFORMANCE

Numerous studies have been performed over the last 50–60 years concerning the relationship between ascorbic acid intake and improvement of physical performance. Many of these studies have found positive effects and an equal number have found no effects. It should be noted that many positive studies were performed early in the study of this vitamin. These studies suffer from poor control and dubious statistical analyses. In addition, the initial vitamin C status of the subjects was usually not ascertained and could have been low. However, several “no effect” articles could be criticized for giving ascorbic acid doses that were probably too low to have possible ergogenic effects.

#### A. Positive Findings

Studies finding positive effects of vitamin C on performance have been reported for both animal and human subject groups. Several early human studies (prior to 1950) did report positive effects of vitamin C in the diet on physical performance including such findings as delayed muscular fatigue and an increase in the amount of work performed.
Ascorbic Acid

Several studies performed since 1960 also have reported positive performance changes in subjects given additional ascorbic acid. Hoogerwerf and Hoitink74 worked 33 untrained male students on a cycle ergometer at 120 watts for 10 minutes. The study was performed in a double-blind manner with 15 students receiving 1,000 mg of ascorbic a day for 5 days while the rest of the students received a placebo. Blood ascorbate concentrations in the subjects were within normal range at the beginning of the study. The researchers found that excess metabolism due to work decreased and mechanical efficiency increased significantly in the group receiving ascorbic acid as compared with the placebo group. Margolis75 studied 40 adult male workers; half of the subjects received a vitamin C supplement of 100 mg while the other subjects served as controls. The authors concluded that the vitamin C supplement was helpful in reducing fatigue and in increasing or preventing a decrease in muscular endurance. Spiroch et al.76 gave 30 healthy men 500 mg of ascorbic acid intravenously prior to a 5-minute step test. Oxygen consumption was reduced by 12%, oxygen debt by 40%, total energy output by 18% and pulse rate by 11% compared with the same test without ascorbic acid. Mechanical efficiency also improved in the subjects when they received the ascorbic acid. Meyer et al.77 investigated the effect of a predominately fruit diet containing 500–1000 mg of vitamin C on the athletic performance of six male and three female university and high school students. All students performed 1 hour of exercise and a 20-km run each day. Measurements were taken before, during and after the diet, which was continued for 14 days. Running times of the students were reduced following the diet but no changes were noted for resting heart rate. Howald et al.78 studied 13 athletes undergoing a moderately intense continuous training program. The athletes were initially given a placebo for 14 days. This was followed by a vitamin C supplement of 1,000 mg/day for the next 14 days. Exercise tests were performed at the end of each dietary period. The exercise test was a progressive cycle ergometer test starting at a workload of 30 watts and increasing in 40-watt increments every 4 minutes until the subject reached exhaustion. Subjects exhibited a significantly greater physical working capacity at a heart rate of 170 beats/minute. In addition, heart rates were consistently lower at each workload throughout the progressive test when the subjects were receiving the vitamin C. Finally, the addition of vitamin C to the diets of a group of trained Indian university women also resulted in an improvement in their VO₂max and work efficiency in the Harvard step test.79

B. STUDIES SHOWING NO EFFECT

While many studies do report an ergogenic effect of ascorbic acid, an almost equal number have found no effect of supplementing the vitamin on performance.

Several studies conducted prior to 1960,80–85 as well as a number of newer studies, found no effect of vitamin C on performance. Rasch86 found no differences in performance of cross-country runners receiving either 500 mg of vitamin C/day or a placebo. The experiment lasted one cross-country season, and diets during this time were not controlled. Margaria et al.87 administered 240 mg of vitamin C to subjects 90 minutes before exercise. These authors found no effects of the vitamin on treadmill run time to exhaustion or VO₂max as compared with control conditions. Snigur88 studied school children for a period of 2 years. Half of the children were given an ascorbic acid supplement of 100 mg a day and the rest of them acted as controls. Normal dietary vitamin C intake of the children was calculated at 40 mg/day. No differences between groups were seen for fatigability as estimated by strength of the wrist muscles or vital capacity of the lungs. Another investigator89 gave subjects a vitamin C supplement or a placebo in a double-blind protocol and exercised them on a motor-driven treadmill. No differences were noted for oxygen consumption, respiratory quotient, pulse or respiratory rate. Gey et al.90 used 286 soldiers as subjects in an experiment that lasted for 12 weeks. Subjects were administered 1,000 mg of vitamin C or a placebo in a double-blind manner. No differences were seen for endurance performance or overall improvement as measured by the mean distance covered on a 12-minute walk/run test. Bailey et al. conducted two studies91,92 in which young male subjects were exercised

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on a level motor-driven treadmill at various speeds. The experiments were conducted in a double-blind manner with subjects receiving either 2,000 mg of ascorbic acid or a placebo for 5 days. No differences were noted for minute ventilation, oxygen uptake, oxygen pulse or respiratory variables. In yet another study, the effects of giving 250–1,000 mg of ascorbic acid, either as a supplemental tablet or by drinking orange juice, was evaluated in normal athletic subjects. A placebo and untreated control group were included. No differences were noted among groups for sprint times, long-distance running or work efficiency as measured by the Harvard step test. Horak and Zenisek gave two groups of well-trained athletes either 200 mg of ascorbic acid daily as a supplement or a diet high in vitamin C foods. These authors reported no significant relationship between resting vitamin C concentrations and work efficiency.

Keren and Epstein reported on the effects of a vitamin C supplement on both anaerobic and aerobic performance. Ascorbic acid at 1,000 mg/day or a placebo were given in a double-blind manner for 21 days to a group of male subjects undergoing training. No differences were noted for \( \text{VO}_2 \text{max} \) or anaerobic performance. Keith and Merrill reported no differences in maximum grip strength or in muscular endurance in 15 male subjects receiving either a single dose of 600 mg of vitamin C or a placebo given 4 hours prior to exercise. Mean muscular endurance values were actually worse on the vitamin C supplement, although this value was not significantly different. The experiment was performed using a double-blind crossover protocol. Normal vitamin C intake of the subjects was calculated to be 140 mg/day. Keith and Driskell found no differences in forced expiratory volume, vital capacity, treadmill workload, resting heart rate or post-exercise lactic acid in a group of male subjects receiving 300 mg of ascorbic acid versus a group receiving a placebo for 21 days. The study was conducted in a double-blind crossover manner with a 3-week washout period between treatments. Subjects had normal plasma ascorbic acid concentrations at the beginning of the study. In a final study for this section, Driskell and Herbert administered 1,000 mg of ascorbic acid daily or a placebo to male subjects undergoing treadmill testing. The experiment lasted 6 weeks. No significant differences were noted for a variety of performance measures.

Summarizing the data on ascorbic acid as a possible ergogenic aid is difficult. Several studies report an ergogenic effect while just as many studies cite no effect. Weaknesses can be found in studies taking both points of view. However, several of the later studies, in which initial vitamin C status was apparently adequate and supplemental vitamin C was given at 200–1000 mg, seemed to show no ergogenic effects of additional vitamin C. While exceptions may be found, supplemental vitamin C, when given to well-nourished subjects, would seem to have no pronounced or consistent ergogenic effects.

### IV. DIETARY INTAKES OF ASCORBIC ACID IN PHYSICALLY ACTIVE PERSONS

Numerous studies have reported on the vitamin C intake of different types of male and female athletes. These studies are summarized in Table 2.5. Generally, mean vitamin intakes in these groups were above the DRI/RDA. The range of mean vitamin C intakes for males was 94 to 600 mg/day, while female athletes had intakes of 55 to 847 mg/day. Almost all studies reported mean vitamin C intakes in athletes to be above the RDA and at levels that would probably be considered adequate or good for athletes under most conditions.

However, while mean intakes for the athletic groups were generally adequate, several studies did report that a portion of their athletic population consumed ascorbic acid in suboptimal amounts. In male athletes, Steen and McKinney reported that 23% of their wrestlers consumed less than two thirds of the RDA for vitamin C. Other papers have indicated similar figures:

- Hickson et al., 12–20% of football players below 2/3 RDA.
- Guillard et al., 25% with low intakes.
- Cohen et al., 10% of dancers below the RDA.
- DeBolt et al., reported that 10% of Navy SEALS were below the RDA.
### TABLE 2.5
Mean Dietary Intakes (mg/day) of Vitamin C in Various Athletic Groups

<table>
<thead>
<tr>
<th>Athletic Group</th>
<th>Subject Number</th>
<th>Vitamin C Intake</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance runners</td>
<td>15</td>
<td>219</td>
<td>99</td>
</tr>
<tr>
<td>Marathon runners</td>
<td>291</td>
<td>147</td>
<td>100</td>
</tr>
<tr>
<td>High school footballers</td>
<td>134</td>
<td>180</td>
<td>101</td>
</tr>
<tr>
<td>Competitive runners</td>
<td>30</td>
<td>109</td>
<td>35</td>
</tr>
<tr>
<td>Basketball players</td>
<td>16</td>
<td>184</td>
<td>102</td>
</tr>
<tr>
<td>Elite triathletes</td>
<td>20</td>
<td>275</td>
<td>103</td>
</tr>
<tr>
<td>Compet. bodybuilders</td>
<td>13</td>
<td>272</td>
<td>104</td>
</tr>
<tr>
<td>Various athletes</td>
<td>55</td>
<td>95</td>
<td>36</td>
</tr>
<tr>
<td>Cross country runners</td>
<td>12</td>
<td>262</td>
<td>105</td>
</tr>
<tr>
<td>Swimmers</td>
<td>22</td>
<td>186</td>
<td>106</td>
</tr>
<tr>
<td>Ice hockey players</td>
<td>48</td>
<td>161</td>
<td>107</td>
</tr>
<tr>
<td>Elite Nordic skiers</td>
<td>5</td>
<td>282</td>
<td>108</td>
</tr>
<tr>
<td>Elite ballet dancers</td>
<td>10</td>
<td>170</td>
<td>34</td>
</tr>
<tr>
<td>Ultramarathoners</td>
<td>82</td>
<td>520</td>
<td>58</td>
</tr>
<tr>
<td>Elite Nordic skiers</td>
<td>13</td>
<td>232–371 (R)</td>
<td>109</td>
</tr>
<tr>
<td>College athletes</td>
<td>—</td>
<td>97–433 (R)</td>
<td>110</td>
</tr>
<tr>
<td>College soccer</td>
<td>18</td>
<td>252,529</td>
<td>111</td>
</tr>
<tr>
<td>Navy SEALS</td>
<td>267</td>
<td>353</td>
<td>112</td>
</tr>
<tr>
<td>Gaelic footballers</td>
<td>25</td>
<td>73</td>
<td>120</td>
</tr>
<tr>
<td>Professional soccer</td>
<td>21</td>
<td>94</td>
<td>121</td>
</tr>
<tr>
<td>Elite soccer</td>
<td>8</td>
<td>520</td>
<td>122</td>
</tr>
<tr>
<td>Elite alpine ski racers</td>
<td>12</td>
<td>600</td>
<td>123</td>
</tr>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon runners</td>
<td>56</td>
<td>115</td>
<td>100</td>
</tr>
<tr>
<td>University dancers</td>
<td>21</td>
<td>148</td>
<td>113</td>
</tr>
<tr>
<td>College basketball</td>
<td>10</td>
<td>55</td>
<td>102</td>
</tr>
<tr>
<td>High school gymnasts</td>
<td>13</td>
<td>84</td>
<td>114</td>
</tr>
<tr>
<td>College basketball</td>
<td>13</td>
<td>106</td>
<td>115</td>
</tr>
<tr>
<td>College gymnasts</td>
<td>9</td>
<td>207</td>
<td>115</td>
</tr>
<tr>
<td>Compet. bodybuilders</td>
<td>11</td>
<td>196</td>
<td>104</td>
</tr>
<tr>
<td>Swimmers</td>
<td>21</td>
<td>188</td>
<td>106</td>
</tr>
<tr>
<td>Adolescent gymnasts</td>
<td>42</td>
<td>112</td>
<td>107</td>
</tr>
<tr>
<td>Trained cyclists</td>
<td>8</td>
<td>80</td>
<td>116</td>
</tr>
<tr>
<td>Elite Nordic skiers</td>
<td>7</td>
<td>234</td>
<td>108</td>
</tr>
<tr>
<td>Elite ballet dancers</td>
<td>12</td>
<td>162</td>
<td>34</td>
</tr>
<tr>
<td>Adolescent ballerinas</td>
<td>92</td>
<td>148</td>
<td>117</td>
</tr>
<tr>
<td>Elite Nordic skiers</td>
<td>14</td>
<td>173–210 (R)</td>
<td>109</td>
</tr>
<tr>
<td>Various college athletes</td>
<td>—</td>
<td>84–223 (R)</td>
<td>110</td>
</tr>
<tr>
<td>Adolescent volleyball</td>
<td>65</td>
<td>93</td>
<td>124</td>
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<tr>
<td>Artistic gymnasts</td>
<td>29</td>
<td>847</td>
<td>125</td>
</tr>
<tr>
<td>Elite heptathletes</td>
<td>19</td>
<td>151</td>
<td>126</td>
</tr>
</tbody>
</table>

*Note: R = range, instead of mean.*
Female athletes show similar figures:

- Nowak et al. reported mean intakes of a group of basketball players to be below the RDA.
- Hickson et al. found 13–22% of basketball players and gymnasts to be below 2/3 RDA.
- Keith et al. showed that 25% of the cyclists in their study consumed less than 2/3 RDA.
- Loosli et al. found 10% of gymnasts to be below 2/3 RDA.
- Cohen et al. and Benson et al. found 8–25% of surveyed dancers to be consuming vitamin C at less than the RDA.

Thus, while group means for intake of vitamin C appear to be acceptable, anywhere from 10 to 25% of an athletic group may be consuming suboptimal levels of the vitamin as compared with the RDA. Improved dietary intakes would be needed in these athletes to assure adequate physical performance. It also should be noted that the above listed percentages were based on the previous RDA for vitamin C of 60 milligrams a day. The current RDA for vitamin C has been increased to 75 milligrams for women and 90 milligrams for men. Thus, the percentage of athletes consuming low amounts of vitamin C may actually be greater than the numbers listed in the various studies.

V. SUMMARY AND RECOMMENDATIONS

Historical and scientific evidence demonstrate that vitamin C deficiency or even marginal vitamin C status can adversely affect physical performance. Ascorbic acid can adversely affect physical functioning at several different metabolic sites such as: impaired collagen formation leading to increased ligament and tendon problems; decreased synthesis of carnitine, which would impair the use of fatty acids as an energy source; decreased synthesis of epinephrine and norepinephrine resulting in improper metabolic responses to exercise; as well as improper iron metabolism possibly resulting in anemia and fatigue with consequential decreases in aerobic performance. Thus, all physically active persons should strive to maintain optimal vitamin C status through intake of generous servings of fruits and vegetables high in ascorbic acid, or if this is not possible, through proper supplementation with the vitamin through pills or with foods that have had vitamin C added.

The RDA for vitamin C is 75 mg for adult women and 90 mg for adult men. These values may not be sufficient for athletes engaged in strenuous, prolonged physical activity events and training. Appropriate intakes for these athletes may range from 100 to 1000 mg each day.

Numerous studies have investigated both the effects that exercise has on vitamin C needs and the effect that supplemental vitamin C has on subsequent athletic performance. Several animal and human studies do seem to indicate that strenuous or prolonged exercise or physical training, in all likelihood, increases the need for vitamin C. It is less likely that light or moderate levels of activity and training increase vitamin C requirements. Animal studies consistently show reduced tissue levels of ascorbic acid with exercise. Several human studies have shown reduced plasma and leukocyte concentrations and reduced urinary excretion of the vitamin with exercise. In addition, supplemental dietary vitamin C has been shown to increase adaptation to exercise in the heat and reduce upper respiratory tract infections in individuals undergoing strenuous exercise. Supplemental vitamin C also has been shown, in some studies, to reduce plasma cortisol concentrations and muscle soreness markers following exercise. Vitamin C intake in these studies generally ranged from 100 to 1500 mg/day. Numerous other data from dietary intake studies with athletes show mean vitamin C intakes of most athletic groups to be in the 55 to 850 mg/day range; intakes that are generally above RDA values. However, several of these studies report that up to 25% (or perhaps more) of the athletes consumed vitamin C at less than RDA levels. Thus, while mean ascorbic acid intakes appear to be adequate, a large percentage of athletes could be consuming suboptimal intakes of the vitamin.

Numerous studies have been conducted in an attempt to find possible ergogenic effects of ascorbic acid. The results of these studies are mixed. Many report possible ergogenic effects of
Ascorbic Acid

vitamin C, while just as many studies find no effect of ascorbic acid supplementation on subsequent performance. Most of the more recent, and generally better controlled studies do not seem to indicate an ergogenic effect of vitamin C. At the present time, the data do not seem to support a clear or consistent ergogenic effect of vitamin C.

While a wealth of knowledge does exist concerning ascorbic acid and exercise, many areas remain understudied. The relationship between exercise and vitamin C requirements is still one such area. Most of the work done in this area has been performed with runners. Little or no work has been done that has reported on the relationships between vitamin C requirements and exercise for strength-power athletes, swimmers (who undergo large training volumes) and cyclists. Studies on plasma and leukocyte ascorbic acid concentrations and changes, as well as urine excretion values, cortisol concentration changes and upper respiratory tract infections in these groups have not been performed. Little, if any, work has been performed evaluating how exercise might alter ratios of ascorbic acid and dehydroascorbic acid in tissues. This ratio has been shown to be altered in some disease states. Newer studies looking at the effects of ascorbic acid on heat acclimation need to be done. Heat stress and dehydration are extremely important concerns for many athletes. No studies have investigated the relationship between heat stress and vitamin C for more than 25 years. All of these subjects need to be explored in the future to further our understanding of vitamin C and physical activity.

REFERENCES


Ascorbic Acid

Ascorbic Acid


