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Review Article

Effects of free radicals and antioxidants on exercise performance

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Abstract
Free radicals are very reactive chemical species that can cause oxidation injury to the living beings by attacking the macromolecules like lipids, carbohydrates, proteins and nucleic acids. Antioxidants protect cells from damage caused by unstable molecules known as free radicals. The scope of this review was to critically examine the effect of free radicals and antioxidants on exercise and techniques for positive homeostasis between the two for better exercise performance. Our bodies naturally protect themselves against free radicals with a class of substances called antioxidants. Excess free radical formation has been hypothesized to contribute to cancer, atherosclerosis, aging and exercise associated muscle damage. Regular low to moderate physical exercise enhances the antioxidant defense system and protects against exercise induced free radical damage. Heavy exercise increases the level of free radicals. Free radical production or loss of antioxidant protection can adversely affect performance. Antioxidant supplements such as vitamin C, E and beta-carotene and recently N-acetylcysteine (NAC) have been touted as beneficial for enhancing exercise performance. However, experimental studies seem not to fully support this notion except NAC. It was concluded that people involved in acute or chronic physical exercise programs should avoid overtraining and if they must be engaged in high intensity training, they may benefit from some of the antioxidant supplementation such as NAC. It was recommended that antioxidant food supplements in moderate doses (recommended daily allowance) for both athletes and non-athletes could be encouraged; also that training grounds should be located outside industrialized cities to avoid unnecessary over-production of free radicals.

INTRODUCTION

Free radicals are reactive chemical species, that can cause oxidation injury to the living beings by attacking the macromolecules like lipids, carbohydrates, proteins and nucleic acids. However, antioxidants protect the cells from damage caused by these unstable molecules. Antioxidant nutrients are naturally found in a varied diet of unprocessed grains, vegetables and fruit. These antioxidant nutrients include vitamins A, C, E and several of the B vitamins, the minerals selenium, copper and zinc, bioflavonoids and various antioxidant enzymes. High concentrations of these antioxidant nutrients are found in wheat and barley grass, sprouts and dark green vegetables. Fruit is another good source of antioxidants; the best being blueberries, blackberries and strawberries. The body uses antioxidants to soak up free radicals like sponges. If your body has plenty of antioxidants available, it can minimize the damage caused by free radicals. Under normal physiological conditions, there is a critical balance in the generation of oxygen free radicals and antioxidant defense systems used by organisms to deactivate and protect themselves against free radical toxicity [1, 2]. Impairment in the oxidant/antioxidant equilibrium creates a condition known as oxidative stress. Oxidative stress is known to be a component of molecular and cellular tissue damage mechanisms in a wide spectrum of human diseases [3-5].

Most research has shown that strenuous exercise increases production of harmful substances such as free radicals, which can damage muscle tissue and result in inflammation and muscle soreness. Exercising in cities or smoggy areas also increases exposure to free radicals [6]. Because free radicals are implicated in so many pathologies (such as cancer, atherosclerosis, aging, muscle soreness, inflammation, *etc*), they have become a hot topic of research in recent years. They have also become business words in advertisements for antioxidants such as vitamin C and E, acclaimed for their ability to fight the molecules that damage cells and tissues [7]. Available research indicates that if a food supplement can be beneficial in combating free radicals then vitamin E may be the most effective [8].

Normally, there is delicate balance between free radicals (oxidants) and antioxidants in the biological systems. Both are essential for converting food into energy. Yet exercise, like disease, can tip the balance towards excessive free radical production. Moderate exercise is a healthy practice; exercise increases oxygen consumption, and exhaustive exercise can generate free radicals. When exercise is halt, normal blood flow resumes and tissues become re-oxygenated. This re-oxygenation of oxygen-deprived tissues still generates more free radicals [9]. Therefore, the purpose of this review was to critically examine the effect of free radicals and antioxidants on exercise performance and techniques for positive homeostasis between the two for better exercise performance.

FREE RADICALS

Oxidative stress is defined as excessive production of reactive oxygen species (ROS) in the presence of diminished antioxidant substances [10]. Free radicals are atoms or group of atoms with an odd (unpaired) number of electrons and can be formed when oxygen interacts with certain molecules. Once formed these highly reactive radicals can start a chain reaction, like dominoes. Their chief danger comes from the damage they can do when they react with important cellular components such as DNA, or the cell membrane. Cells may function poorly or die if this occurs [11].

Free radicals are by-products of cellular activity that can damage other cells or cause undue stress to the body. The body naturally produces chemicals called free radicals that cause irreversible damage (oxidation) to cells [12]. Free radicals are synonyms with damage. They damage everything they come in contact with. They do their damage insidiously, silently and invisibly. This damage is also called “oxidation” (loss of electrons). Free radical damage leads to loss of energy, disease, pain, aging and eventually death [11].

Sources of free radicals

Free radicals and other reactive species are constantly generated in the human body. Some are made by ‘accidents of chemistry’; for example, leakage of electrons directly on to O_2 from the intermediate electron carriers of the mitochondrial electron transport chain generates a steady stream of O_2. Secondly, exposure of living organisms to ionizing radiation splits the H-O-H bonds in water (the major constituent of living cells) to generate OH^- and H^+. The hydroxyl radical (OH•) reacts at a diffusion-controlled rate with almost all molecules in living cells. Hence, when OH• is formed *in vivo*, it damages whatever it is generated next to; it cannot migrate any significant distance within the cell [1, 13].

The source of oxidative stress is a cascade of ROS leaking from the mitochondria [13]. According to Blumberg *et al* [14] the primary source of the free radicals is generally regarded as being the mitochondria, organelles within the cells which are responsible for the oxidation of most foodstuffs to generate energy. However, they may not be the only source. The following events may also be relevant to this problem [15]:

-Tissues that are mechanically injured during strenuous exercise are subject to inflammation. This may attract neutrophils and other immunological active substances to the injury site. Many of these substances release free radicals as a mechanism to kill bacteria and other foreign invaders.

-Damaged cellular constituents need to be degraded and removed; therefore lysosomes and other protein “digestive” enzymes may be concentrated at the injury site.

-There is some evidence that tissues that are temporarily deprived of their blood supply can attract a cascade of reactions leading to the production of free radicals.

Free radicals *in vivo*

Indeed, the harmful effects of excess exposure to ionizing radiation on living organisms are thought often to be initiated by attack of OH• on proteins, DNA and lipids. For example, lipids undergo lipid peroxidation and the 8-hydroxyguanine radical can lose one electron to form the mutagenic oxidized base 8-hydroxyguanine (which produces GC TA transversion mutations). Whereas OH• is probably always harmful, other (less reactive) free radicals may be useful in vivo:

-Thus, nitric oxide (NO) is synthesized from the amino

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acid L-arginine by vascular endothelial cells, phagocytes, and many other cell types. Nitric oxide has multiple functions: for example, it helps to regulate blood pressure and may be involved in the killing of parasites by macrophages.

-The superoxide radical ($O_2•^−$), the one-electron reduction product of oxygen, is produced by phagocytic cells and helps them to kill bacteria. Evidence is accumulating to suggest that smaller amounts of extracellular $O_2•^−$ may be generated, perhaps as intercellular signal molecules, by several other cell types, including endothelial cells, lymphocytes and fibroblasts. Superoxide may also be involved in the 'sensing' of blood O_2 levels by the carotid body [1, 13].

Types of oxygen radicals

There are many types of radicals, but those of most concern in biological systems are derived from oxygen, and known collectively as ROS. Oxygen has two unpaired electrons in separate orbital in its outer shell. This electronic structure makes oxygen especially susceptible to radical formation. The reactive oxygen species produced in cells include [16]:

-Hydrogen peroxide (H_2O_2)

-Hypochlorous acid (HOCl)

-Hydroxyl radical (OH•)

-Superoxide anion ($O_2•^−$).

Mechanism of free radicals' production and action

Free radicals are produced under certain environmental conditions and during normal cellular function in the body. These molecules are missing an electron, giving them an electric charge [17]. To neutralize this charge, free radicals try to take out ("stealing") an electron from or donate an electron to a neighboring molecule. This process, called oxidation, creates a new free radical from the neighboring molecule. The newly created free radical, in turn, searches out another molecule and steals or donates an electron, setting off a chain reaction that can damage hundreds of molecules [17]. Some free radicals arise normally during metabolism. Sometimes the body's immune system cells purposefully create them to neutralize viruses and bacteria. However, environmental factors such as pollution, radiation, cigarette smoke and herbicides can also spawn free radicals [18]. Normally, the body can handle free radicals, but if antioxidants are unavailable, or if the free-radical production becomes excessive, damage can occur. Of particular importance is that free radical damage accumulates with age [17-19].

Excessively high levels of free radicals cause damage to cellular proteins, membrane lipids and nucleic acids, and eventually cell death [20]. Various mechanisms have been suggested to contribute to the formation of these reactive oxygen-free radicals. Glucose oxidation is believed to be the main source of free radicals. Glucose is oxidized in a transition metal-dependent reaction to an enediol radical anion that is converted into reactive ketoaldehydes and to $O_2•^−$. The $O_2•^−$ undergo dismutation to H_2O_2, which if not degraded by catalase or glutathione peroxidase, and in the presence of transition metals, can lead to production of extremely reactive OH• [21]. Superoxide anion radicals can also react with NO to form the reactive molecule peroxynitrite ($ONOO^−$) [22]. Hyperglycemia is also found to promote lipid peroxidation of low density lipoprotein (LDL) by a superoxide-dependent pathway resulting in the generation of free radicals [23].

Physiologic role of free radicals

Free radicals, however, are naturally produced by some systems within the body and have beneficial effects that cannot be overlooked. The immune system is the main body system that utilizes free radicals. Foreign invaders or damaged tissues are marked with free radicals by the immune system. This allows for determination of which tissue need to be removed from the body [24].

Individuals susceptible to free radical damage

It has been suggested that older individuals may be more susceptible to free radical damage; individuals with antioxidant nutrient deficiencies are more susceptible to danger. Several conditions may contribute to an individual being at increased oxidative stress status, *e.g.* people who smoke cigarettes, live in areas with significant air pollutions, or have certain diseases associated with elevated oxidative stress status such as diabetes. People who are regularly involved in strenuous exercise may also be particularly susceptible to free radical damage [15].

Measuring free radicals

Free radicals have a very short half-life, which makes them very hard to measure in the laboratory. Multiple methods of measurement are available today, each with their own benefits and limits. Radicals can be measured using the following methods:

-***Electron spin resonance and spin trapping methods:*** electron spin resonance (ESR) is by far the best available technique for detection and characterization of free radicals. Electron spin resonance and spin trapping methods are both very sophisticated and can trap even the shortest-lived free radical. Exogenous compounds with a high affinity for free radicals (*i.e.* xenobiotics) are utilized in the spin techniques. The compound and radical together form a stable entity that can be easily measured. This indirect approach has been termed "fingerprinting" [25]. However, this method is not 100% accurate. Spin-trapping collection techniques have poor sensitivity, which can skew the results [26].

-***Markers of oxidative stress:*** a commonly used alternate approach measures markers of free radicals rather than the actual radical. These markers of oxidative stress are measured using a variety of different assays. These assays are described below. When a fatty acid is peroxidized it is broken down into aldehydes, which are excreted. Aldehydes such as thiobarbituric acid reactive substances (TBARS) have been widely accepted as a general marker of free radical production [27]. The most commonly measured TBARS is malondialdehyde (MDA) [28]. The TBA test has been challenged because of its lack of specificity, sensitivity, and reproducibility.

-Lastly, ***conjugated dienes (CDs)*** are often measured as indicators of free radical production. Oxidation of unsaturated fatty acids results in the formation of CDs. The measured CDs provide a marker for the early stages of lipid peroxidation. This newly developed technique for measuring free radical production shows promise in producing more valid results. The technique uses monoclonal antibodies and may prove to be the most accurate measurement of free radicals. However, until further more reliable techniques are established it is generally accepted that two or more assays be utilized whenever possible to enhance validity [13].

-On the other hand, the ratio of total oxidative status (TOS) to total antioxidant capacity (TAC) is accepted as the ***oxidative stress index (OSI)***. For calculation, the resulting unit of TAC was converted to mmol/l, and the OSI value was calculated according to the following formula [29]:

$$\textbf{OSI (arbitrary units)} = \frac{\textbf{TOS } (\boldsymbol{\mu}\textbf{mol } \mathbf{H_2O_2} \textbf{ Eq/l})}{\textbf{TAC (mmol Trolox Eq/l)}}$$

Free radical generation in exercise

Endurance exercise can increase oxygen utilization from 10-20 times over the resting state. This greatly increases the generation of free radicals, prompting concern about enhanced damage to muscles and other tissues [30]. In people who exercise rather intensively, particularly older people, free radical production can go into overdrive after intense exercise and end up "chewing up more tissue" than it repairs [7].

Intense exercise in untrained individuals overwhelms defenses resulting in increased free radical damage. Thus, the "week-end warrior" who is predominantly sedentary during the week but engages in vigorous bouts of exercise during the weekend may be doing more harm than good. To this end there are many factors which determine whether exercise induced free radical damage occurs, including degree of conditioning of the athlete, intensity of exercise, and diet; ultra-running produces free radicals [31].

It has been speculated that free radicals may play a role in muscle damage associated with eccentric muscle activity, evidence have shown that unaccustomed and strenuous exercise induces an imbalance between free radical production and the body's antioxidant defense system. Free radical production or loss of antioxidant protection can adversely affect performance [15, 24].

Reactive oxygen/nitrogen species and exercise

It has become clear that skeletal muscle contraction stimulates both reactive oxygen and nitrogen species (ROS/RNS) [32]. Despite early concerns surrounding the possible negative influence of ROS and RNS on skeletal muscle structure and function, it is now clear that these free radicals play an important role in the physiological adaptation of skeletal muscle to exercise [33]. Indeed, the production of free radicals has been associated with disuse atrophy of skeletal muscles [34], whilst moderate increases in reactive species production allow for the cellular signaling pathways required for mitochondrial biogenesis, amongst others. It may therefore be suggested that acute increases in ROS and/or RNS may have positive roles in the adaptive response to exercise, whilst prolonged increases in ROS and RNS may result in the activation of signaling cascades associated with skeletal muscle tissue breakdown, such as the observations in the aged population [35].

Effects of habitants exercise on one's resistance to free radical damage

Regular low (exercise intensity of 40 to 60% maximal heart rate; HRmax) to moderate (exercise intensity of 60-75% HRmax) exercise increases cellular antioxidant defenses. This action may involve several different mechanisms including enhanced antioxidant enzyme activity and changes in protective immune responses. Heavy exercise (exercise intensity of 75-90% HRmax) may deplete the pool of antioxidant vitamins, and people who exercise habitually need to watch their diets carefully, and simply not assume that a "normal balanced diet" is adequate to provide sufficient antioxidant protection. With training there is an enhanced antioxidant enzyme defense system. The more trained an individual is the more likely they are to be able to encounter an increase in free radicals generated by exercise. The "week-end warrior", who may exercise strenuously, only on occasion, may be most at risk for oxidative damage to cells [15, 36]. Weight training, even at low intensities, provides protection from free radicals. Weight lifting protects the body against damage from free radicals. Low to moderate intensity exercise is better than high intensity exercise as the level of free radicals decreases with low intensity exercise and increases minimally with high intensity exercise; with no exercise, there is a high increase in the level of free radicals [7].

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ANTIOXIDANTS

Antioxidants halt the chain reactions of oxidation. Some antioxidants donate electron to stabilize and neutralize the dangerous free radicals [37]. Other antioxidants work against the molecules that form free radicals, destroying them before they can begin the domino effect that leads to oxidative damage [38]. Antioxidants work to control the levels of free radicals before they do oxidative damage to the body. For example, certain enzymes in the body, such as superoxide dismutase, work with other chemicals to transform free radicals into harmless molecules [38]. Dietary antioxidants supplement the action of enzymes that occur naturally in the body, and some studies show that a diet high in foods that are rich in antioxidants may decrease the risk of cancer and heart disease [14, 39]; this idea has been tested in clinical trials but does not seem to be true, since antioxidant supplements have no clear effect on the risk of chronic diseases [40]. This suggests that these health benefits may come from other substances in fruits and vegetables or from a complex mix of substances [41, 42]. Studies are inconclusive, however, and research into the health benefits of antioxidants is ongoing.

The body's defense against oxidative stress is accomplished by interconnecting systems of antioxidant micronutrients (vitamins and minerals) and enzymes. While the vitamins act as donors and acceptors of ROS, minerals regulate activity of the enzymes [10]. Antioxidants are simple substances that prevent, neutralize, or kill free radicals. More specifically antioxidants are vitamins, minerals, coenzymes and herbs that help the body to fight and prevent damage from toxins and free radicals. In doing this, they protect cells, the genetic code and the immune system [11].

Science has demonstrated that athletes or persons engaging in prolonged or intense exercise need higher levels of antioxidants than sedentary people. After intense exercise, free radical production is high, and a good antioxidant formula can improve athletic performance, assist in recovery from intense exercise and support optimal immune function. A potent antioxidant formula is a must for everyone who is exercising, especially athletes [25].

Mechanism of antioxidants

According to Speakman [11], antioxidants prevent free radicals from doing their damage in several ways. Antioxidants can prevent free radicals from forming, protect cells from free radical damage, bind to free radicals and inactivate or kill them and enhance the body's defense system [11]. Antioxidants work to protect lipids from peroxidation by radicals, they are effective because they are willing to give up their own electrons to free radicals. When a free radical gains the electron from an antioxidant it no longer needs to attack the cell and the chain reaction of oxidation is broken [6].

Recovery is also an important application of antioxidant use. Because antioxidants protect against cell and tissue damage, sufficient antioxidant levels in the body will lead to less oxidative damage to muscles. This translates into reduced muscle soreness and faster recovery after intense exercise [25]. Antioxidant supplementation has proven very valuable in effort to protect us from free radical damage. Given that high-intensity exercise can increase free radical production, antioxidant supplements may offer benefit during prolonged aerobic activity [30]. Antioxidant supplementation is likely to provide beneficial effects against exercise induced oxidative tissue damage [43].

Basic antioxidants

-Vitamin E (alpha-tocopherol): is the most abundant fat soluble antioxidant in the body; primary defender against oxidation and lipid peroxidation. The recommended dietary allowance (RDA) for both men and women is 15 mg/day of alpha-tocopherol. Obtaining sufficient vitamin E from the average diet is difficult; supplements can make up the difference. Foods containing high levels of vitamin E are vegetable oils [25, 30]

-Vitamin C (ascorbic acid): is a water soluble antioxidant that directly scavenges some free radicals and recycles vitamin E. It may reduce pains and speed up muscle strength recovery after intense exercise [31]. Supplementation with vitamin C can reduce the amount of muscle damage, which occurs during training. By incurring less muscle damage, athletes may in turn, be able to train more intensely and achieve greater levels of performance [44]. The RDA of vitamin C is 90 mg/day for men and 75 mg/day for women [25]. Foods containing high levels of vitamin C are fresh fruits and vegetables.

-Beta-carotene: is a water soluble precursor to vitamin A, but is an antioxidant in itself. Foods containing high levels of carotene are fruit, vegetables and eggs [25].

-Selenium: is an essential trace element in the diet. It functions through selenoproteins, several of which have antioxidant functions, and includes enzymes such as glutathione peroxidase, a potent free radical scavenger. It acts to destroy peroxides and thus protects lipid membranes as doe's vitamin E [40]. Its RDA is 55 mg/day for both men and women [25].

-Flavonoids: act as antioxidants by directly scavenging free radicals, chelating reactive elements such as iron, or by inhibiting oxidative enzymes [25]. No daily requirement for flavanoids has been established, but a balanced diet containing fresh fruit, vegetables, tea and moderate amounts of red wine (or grape juice) is recommended [44].

-Superoxide dismutase: is an enzyme that, in concert with another enzyme catalase, can disarm and destroy free radicals, particularly $O_2\bullet^-$ [25].

-Glutathione: minimizes the damage caused by free radicals, and is very important for the health of cells [9].

-Coenzyme Q_{10} (ubiquinone)*:* is a "vitamin-like substance" whose role in the function of the electron transport chain (ETC) is well established. CoQ_{10} also has purported antioxidant properties [45].

-Lactic acid: The fermented products of lactic acid can be taken as an antioxidant nutritional supplement for the elders, infants, pregnant women and individuals with malnutrition. More important, the inexpensive fermented products can be used as a good protein source in many developing countries where protein deficiencies remain a major health problem, especially for children [46, 47].

-N-acetylcysteine (NAC): presents two potential, important features in exercise-related issues: ***(1)*** fatigue can be reduced by NAC supplementation; and ***(2)*** the effect depends on the exercise protocol in that the effect is larger with submaximal contractions. Accordingly, a later study showed a beneficial effect of NAC during fatigue induced by repetitive submaximal handgrip exercise but not during maximal contractions [48]. The specific effect of NAC on submaximal contractile force has also been extended to cycling exercise [49-51]. NAC has been shown to have beneficial effects on contractility and fatiguability of human ventilatory muscles [52]. Using the murine diaphragm contracting *in situ,* Shindoh *et al* [53] measured a beneficial effect of NAC on fatigue resistance. They speculated that the mechanism of action could be through NAC effects on blood flow or directly on the muscle fibers themselves. Similar effects on fatigue resistance in the diaphragm have been reported by other groups [54-56]. Results from isolated diaphragm strips contracting *in vitro* indicate that the effects of NAC on fatigue resistance are at the muscle fiber level [54, 55]. Furthermore, using diaphragm bundles contracting *in vitro,* Mishima *et al* [57] reported less fatigue in fibers treated with NAC and this effect was independent of changes in sarcoplasmic reticulum (SR) Ca^{2+} release and uptake.

Side effects of antioxidants

As of yet, there have been no reported or known side effects from taking antioxidant formulas. Thus no adverse side effects should be encountered. However, those that are allergic to certain ingredients should carefully read all labels before taking any antioxidant supplement [25].

Though, it has become "common knowledge" that ROS and RNS generated during exercise are bad, and the usage of antioxidant supplements to ameliorate their effects promotes health. The various makers of dietary supplements have taken full advantage of this phenomenon by including antioxidants in their supplements; or as concentrated products. However, experimental evidence shows that increased ROS production is not necessarily bad: ROS are important for a wide range of normal exercise-related physiological processes, including a role in contraction-mediated glucose uptake [58] and promotion of the adaptive responses to training [59]. Accordingly, the use of antioxidants has been shown to blunt training responses [60-62].

Vitamins C and E with ubiquinone are "expected" to improve exercise performance based on their antioxidant properties and are commonly used by athletes and active individuals. However, experimental evidence to support beneficial effects on physical performance does not exist. However, NAC has been shown to have beneficial effects on contractility and fatigability of human respiratory muscles without any side effect recorded [51, 52].

Exercise and antioxidants for the elderly population

The free radical theory of aging implies that antioxidants such as vitamins A, C and E, beta-carotene and superoxide dismutase will slow the process of aging by preventing free radicals from oxidizing sensitive biological molecules or reducing the formation of free radicals. The antioxidant chemicals found in many foods are frequently cited as the basis of claims for the benefits of a high intake of vegetables and fruits in the diet. Nonetheless, some recent studies tend to show that antioxidant therapy have no effect and can even increase mortality [63]. Since many different substances operate synergistically in antioxidant defence, its complicated process may require more sophisticated approaches to determine if antioxidant therapy may benefit the aging process. The addition of antioxidants can lead to a decrease of normal biological response to free radicals and lead to a more sensitive environment to oxidation [64]. Furthermore, a recent study tracking the eating habits of 478,000 Europeans suggests that consuming lots of fruits and vegetables has little if any effect on preventing cancer [65].

The duration of an exercise program should start with short periods and gradually progress in length. During the initial stage, it may be difficult for some old adults with physiologic limitations to perform exercise for 20 min. It will be possible for them to perform exercise in shorter sessions of five to 10 min repeated several times throughout the day. In addition to the duration of the exercise program itself, elderly people need additional warm-up and cool-down time, perhaps as

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much as 10 min or more. Aerobic exercise 3-5 days per week and moderate intensity exercise is recommended. Although lower intensity exercise with longer duration is recommended for the older adult as it may reduce the risk of injury and provide the needed benefits to the cardiovascular and skeletal muscle (central and peripheral systems). Furthermore, any exercise that is in excess of the aforementioned recommendation may set the stage for oxidative stress and injury. The mode of exercise for the older population should be activities with low impact on their joints. The activities include walking, stationary cycling, water exercise, swimming, or machine-based stair climbing. The activity needs to be accessible, convenient, and enjoyable to the participant [32, 34].

CONCLUSION AND RECOMMENDATIONS

Exercise is an essential part of healthy life, but antioxidant nutrition should also be included as a part of this healthy lifestyle. Common knowledge suggested that people involved in acute or chronic physical exercise programs may benefit from antioxidant supplementation. However, experimental evidence does not support the “common knowledge” that antioxidant treatment greatly improves exercise performance and recovery. Also, studies with antioxidant supplementations generally show no effect on muscle function during and after exercise. The exception is NAC treatment, which has been found to improve performance during submaximal exercise [48-57]. By far, the most promising studies about antioxidants and exercise have centered on vitamin C and E. It has been reported that vitamin E and C reduces free radical production and oxidation related to exercise [66]. However, these beneficial effects could also jeopardize other adaptive benefit of exercise training. The long term effect of large doses of these nutrients has not been proven. Available evidence points to the benefits of food-derived antioxidants, but more evidences are needed before antioxidant or enzyme supplementation can be routinely recommend-ded for people engaging in prolonged exercise.

Based on this review, the followings could be recommended:

-Exercise physiologists, sports medical practitioners, physiotherapists, nutritionists, sports managers *etc*, should include antioxidants as food supplements for both athletes and non-athletes, at least to derive the general health benefit.

-Exercise physiologists, sports scientists, managers and administrators should locate their training ground outside industrialized cities to avoid unnecessary production of free radicals.

-Those involved in sports and physical planning should endeavour to consider environmental status of stadia or training grounds location thus eliminating the effects of free radical due to pollution in industrialized cities.

-More studies are required on the relationship of antioxidants supplement and exercise performance.

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