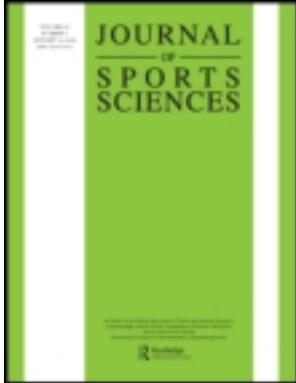


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Could a vegetarian diet reduce exercise-induced oxidative stress? A review of the literature

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Abstract

Oxidative stress is a natural physiological process that describes an imbalance between free radical production and the ability of the antioxidant defence system of the body to neutralize free radicals. Free radicals can be beneficial as they may promote wound healing and contribute to a healthy immune response. However, free radicals can have a detrimental impact when they interfere with the regulation of apoptosis and thus play a role in the promotion of some cancers and conditions such as cardiovascular disease. Antioxidants are molecules that reduce the damage associated with oxidative stress by counteracting free radicals. Regular exercise is a vital component of a healthy lifestyle, although it can increase oxidative stress. **As a typical vegetarian diet comprises a wide range of antioxidant-rich foods, it is plausible that the consumption of these foods will result in an enhanced antioxidant system capable of reducing exercise-induced oxidative stress.** In addition, a relationship between a vegetarian diet and lower risks of cardiovascular disease and some cancers has been established. This review explores the current available evidence linking exercise, vegetarians, antioxidants, and oxidative stress.

Keywords: *Antioxidant, free radical, oxidative stress*

Introduction

Free radicals are reactive atoms or molecules that contain unpaired electrons in their outer valence (Aruoma, 1998; Fang, Yang, & Wu, 2002). The reactive state of free radicals enables them to acquire electrons from a stable molecule and subsequently mediate cell damage (Fang et al., 2002). Antioxidants are compounds capable of reducing the damaging effects that free radicals may provoke by donating electrons to or accepting electrons from a free radical (Thomas, 2000). Dietary sources of antioxidants are classified as exogenous and include nutrients such as vitamin C and vitamin E (Sen, 1995; Serafini, 2006). Endogenous antioxidants are those produced by the body and include enzymes such as catalase, superoxide dismutase, and glutathione peroxidase (Lachance, Nakat, & Jeong, 2001). Oxidative stress describes the physiological state whereby there is an imbalance between free radical production and the ability of the antioxidant defence system of the body to reduce the presence of radicals (Bloomer, Goldfarb, Wideman, McKenzie,

& Consitt, 2005). Undesirable outcomes, such as apoptosis, may arise as a result of oxidative stress (Phaneuf & Leeuwenburgh, 2001). However, oxidative stress is a natural physiological process necessary for some reactions within the body to take place, such as a healthy immune response (Fang et al., 2002; Serafini, 2006) and upregulation of antioxidant defence systems (Child, Wilkinson, Fallowfield, & Donnelly, 1998; Gomez-Cabrera et al., 2006; Powers & Lennon, 1999).

Regular physical exercise can contribute to the maintenance of a healthy body weight and lower blood pressure, thus it can be a key component of a healthy lifestyle (Vuori, 2001). However, research has shown that exercise is associated with the elicitation of oxidative stress (Bloomer et al., 2005; Clarkson & Thompson, 2000; Hudson et al., 2007). To reduce exercise-induced oxidative stress, it has been suggested that individuals consume antioxidant supplements to improve their antioxidant defence system (Barr & Rideout, 2004; Bloomer, Goldfarb, & McKenzie, 2006). A vegetarian diet is typically high in antioxidant-rich food sources such as fruit

and vegetables (Rauma, Torronen, Hanninen, Verhagen, & Mykkanen, 1995), and thus such a diet may have a role in reducing exercise-induced oxidative stress.

Free radicals

Free radicals are reactive compounds, such as nitric oxide, that have one or more unpaired electrons in their valence (Fang et al., 2002). Free radicals can mediate cell damage because they extract electrons from a stable molecule in an attempt to pair up their own electrons, thus leaving the original molecule in an unstable state (Aruoma, 1998; Fang et al., 2002). Molecules of an unstable nature can be described as having an uncontrolled chemistry and can cause damage when they are involved in signal transduction pathways, particularly those required for cell survival (Thomas, 2000). One of the key groups of radicals contains oxygen because it is an electron donor in a number of catabolic, metabolic, and respiration reactions resulting in the production of free radicals (Ji, 1999). Radicals that contain oxygen are called "reactive oxygen species" and include superoxide, hydrogen peroxide, and the hydroxyl radical (Aruoma, 1998; Fang et al., 2002). Together with reactive oxygen species, radicals containing nitrogen, "reactive nitrogen species", are produced under normal and adverse health conditions and may have a role in signal transduction, cell proliferation, and metabolism (Bloomer & Goldfarb, 2004; Fang et al., 2002). Numerous studies have illustrated that exercise can result in an increase in free radical production and that the body's antioxidant defence system plays a pivotal role in reducing the presence of free radicals and reactive oxygen species (Alessio et al., 2000; Bloomer et al., 2005, 2006; Chevion et al., 2003; Coombes et al., 2001; Hudson et al., 2007).

Antioxidants: Function

Antioxidants are molecules that can reduce the impact of oxidative stress (Clarkson & Thompson, 2000; Jackson, 1994). Antioxidants moderate the effect of free radicals on a deoxyribonucleic acid (DNA), carbohydrate or lipid molecule by donating an electron to or accepting an electron from a free radical to make it less reactive (Fang et al., 2002; Sen, 1995). Antioxidants can also function as co-factors to ensure that a suitable oxidation-reduction environment is present so that free radicals can be neutralized (Sen, 1995).

Antioxidants: Classification and source

Antioxidants can be classified as either endogenous, those produced by the body, or exogenous, those

influenced by nutrient intake (Sen, 1995; Serafini, 2006). Exogenous antioxidants are classified as non-enzymatic and include vitamins such as A, C, and E as well as co-factors such as zinc, copper, and selenium (Fang et al., 2002; Sen, 1995; Serafini, 2006). Vitamin E is a fat-soluble vitamin that can be obtained from plant oils such as nuts and seeds (Jiang et al., 2006). Once vitamin E has reduced a free radical it may itself become a radical, then be regenerated to its original form by co-antioxidants and continue its usual antioxidant activity (Coombes et al., 2001; Rietjens et al., 2002). Vitamin C is a water-soluble vitamin contained in fruits and vegetables with the ability to reduce radicals and scavenge reactive oxygen species in an aqueous environment (Powers & Lennon, 1999). Vitamins C and E are important for their antioxidant activity against superoxide, hydroxyl, and lipid peroxy radicals in lipid and cell membrane environments (Intra & Kuo, 2007; Powers & Lennon, 1999). Vegetarian diets may be higher in many of the non-enzymatic antioxidants due to such diets containing larger quantities of foods that are naturally higher in antioxidants, such as nuts, fruits, and vegetables.

Endogenous enzymes such as superoxide dismutase and glutathione peroxidase are components of the body's primary defence that modulate the synthesis of cell signalling molecules and thereby moderate oxidative stress (Aruoma, 1998; Lachance et al., 2001; Sen, 1995; Zafriou, Deva, Ciccoli, Siafaka-Kapadai, & Nigam, 2007). Phospholipid hydroperoxide glutathione peroxidase is an enzyme that can lower hydroperoxide tone, which is needed to activate lipoxygenases (Zafriou et al., 2007). Since lipoxygenases initiate the synthesis of cell signalling molecules, it may be possible to reduce the synthesis of cell signalling molecules by lowering hydroperoxide tone (Brash, 1999; Zafriou et al., 2007). Dietary components such as the micronutrients manganese, zinc, copper, and selenium can be co-factors for endogenous enzymes (Fang et al., 2002). Superoxide dismutase, for example, has zinc, copper, and manganese dependent forms, thus when there is a deficiency of these nutrients the activity of the endogenous enzyme is reduced (Aruoma, 1998; Fang et al., 2002).

Antioxidant status

Antioxidants, both endogenous and exogenous, work to protect the cells of the body against the potentially damaging effects of oxidative stress (Aruoma, 1998; Fang et al., 2002). Antioxidant status can thus be ascertained from the concentration of antioxidant vitamins and minerals in a blood sample (Rauma & Mykkanen, 2000). Smoking (Faruque, Khan, Rahman, & Ahmed, 1995), training

status (Watson, MacDonald-Wicks, & Garg, 2005), ageing (Ji, 2001), and hormone concentrations (Elhadd et al., 2003) are some of the factors that can influence antioxidant status.

A diet rich in antioxidants, such as a vegetarian diet, may improve an individual's antioxidant status (Krajcovicova-Kudlackova et al., 1996; Rauma et al., 1995; Rauma & Mykkanen, 2000; Szeto, Kwok, & Benzie, 2004). Vegetarians have been shown to consistently consume significantly greater quantities of dietary antioxidants than omnivores and may have an improved antioxidant status (Krajcovicova-Kudlackova et al., 1996; Rauma et al., 1995; Szeto et al., 2004). It is important to note that it is plausible for an omnivore diet that incorporates sufficient quantities of fruits and vegetables to result in a similar antioxidant status (Sebekova et al., 2006).

Although susceptible to oxidative stress, proteins such as glutathione and methionine function as antioxidants and thus may contribute to an improved antioxidant status (Levine, Berlett, Moskovitz, Mosoni, & Stadtman, 1999). Recent animal model studies have shown that methionine restriction can increase lifespan and significantly reduce oxidative stress in liver and heart tissue (Ayala et al., 2007; Sanz et al., 2006). Since an omnivore diet is higher in animal-derived protein, it may be possible for such a diet to increase oxidative stress if the protein's pro-oxidant effects outweigh the antioxidant capacity.

Oxidative stress

Oxidative stress is a natural biological phenomenon whereby an imbalance occurs between the quantity of free radicals produced and the ability of the body's antioxidant defence systems to neutralize them (Alessio et al., 2000; Bloomer et al., 2005; Hudson et al., 2007). This imbalance can occur because of an increase in free radical production due to factors such as exercise (Alessio et al., 2000; Bloomer et al., 2005, 2006; Chevion et al., 2003; Coombes et al., 2001; Hudson et al., 2007) and illness (Kennedy et al., 2005). Oxidative stress can also be described as the physiological result of reactive oxygen species being present in quantities that put stress on the body's antioxidant defence system so that the quantity of free radicals present is capable of inducing cell damage (Bloomer et al., 2006; Hudson et al., 2007). The structure of lipids, proteins, and DNA can be altered by reactive oxygen species, which in turn interferes with their normal function (Bloomer et al., 2006; Hudson et al., 2007). Venous blood samples can be analysed for radical content to ascertain the degree of oxidative stress present using several chemical reactions (Davison, Ashton, Davies, & Bailey, 2008; Komatsu et al., 2006). Electron spin resonance spectroscopy used in conjunction with a

spin-trapping technique is recognized as being the most direct method for detection and identification of radicals (Ashton et al., 1998; Davison et al., 2008), while high-performance liquid chromatography is commonly used to quantify plasma malondialdehyde, which is a marker of lipid peroxidation (Ashton et al., 1998). Further free radical analytical systems built with a dedicated photometer and temperature-controlled centrifuge are also available that allow real-time assessment of markers pertaining to oxidative stress, primarily hydroperoxides (Komatsu et al., 2006). An imbalance between the production of free radicals and the antioxidant defence system may be harmful to the body, as radicals can cause cellular damage.

Oxidative stress: Positive aspects

Oxidative stress has a vital role to play in a number of physiological processes (Fang et al., 2002), including contributing to a healthy immune system, as radicals can function as the signalling messengers for many cellular metabolic processes (Fang et al., 2002; Serafini, 2006). The phagocytic immune response, which can be activated during exercise, uses radicals to destroy potentially dangerous microorganisms so that the homeostatic status of the body can be maintained (Leeuwenburgh & Heinecke, 2001; Sen, 1995). Further radicals can play a crucial role in the wound healing process whereby they may induce factors that promote cell growth, development, and differentiation (Sen, 1995). Radicals can react with molecules to induce cell signalling, which is necessary for vital cellular processes, such as metabolism and respiration, to occur (Cooper, Vollaard, Choueiri, & Wilson, 2002). Once the stability, or oxidation-reduction status, of a molecule has been altered by a radical its affiliated cellular signalling cascade changes (Phaneuf & Leeuwenburgh, 2001). Consequently, there can be changes to further signalling processes within the cell, such as those related to cell proliferation, differentiation, and survival (Ji, 1999; Phaneuf & Leeuwenburgh, 2001). By modifying the oxidation-reduction status of molecules or by their presence in a reaction, free radicals can also become intertwined with the processes related to glucose transport and muscle contractions (Balon & Yerneni, 2001; Reid, 2001). The role of reactive oxygen species in glucose transport and muscle contractions can be of interest to athletes, since glucose is a muscle fuel and muscle contractions are needed for exercise to occur (Andrade, Reid, Allen, & Westerblad, 1998; Balon & Yerneni, 2001). Different levels of reactive oxygen species affect muscle contractions in different ways, so that lower concentrations may aid contractions while higher concentrations may play an inhibitory

role (Andrade et al., 1998; Balon & Yerneni, 2001; Reid, 2001). Hence oxidative stress is not always detrimental to the body, as it can be associated with a healthy immune response and aid muscle contractions.

Oxidative stress: Negative aspects

Although oxidative stress can be associated with positive outcomes, it can also lead to undesirable outcomes such as the initiation of cellular death pathways in healthy cells (Phaneuf & Leeuwenburgh, 2001). Apoptosis or programmed cell death can be increased during bouts of acute exercise, as the reactive oxygen species and free radicals produced can damage the mitochondrial proteins and DNA that regulate apoptosis (Phaneuf & Leeuwenburgh, 2001). When apoptosis is not regulated it can be associated with diseases such as cancer, AIDS, Alzheimer's disease, and rheumatoid arthritis (Phaneuf & Leeuwenburgh, 2001). Increased oxidative stress activity is also associated with a number of degenerative disease pathologies, such as cell ageing, cataract formation, atherosclerosis (Aruoma, 1998; Lachance et al., 2001), muscular dystrophy, cancers such as lung cancer, type 2 diabetes, and Parkinson's disease (Aruoma, 1998; Bloomer et al., 2006; Sen, 1995), thus research into the area of minimizing the negative impact of oxidative stress is of interest to health professionals.

The increased presence of free radicals and reactive oxygen species evident during oxidative stress has a pivotal role in lipid peroxidation, which is associated with the development of atherosclerosis (Madamanchi, Vendrov, & Runge, 2005; Sen, 1995). Atherosclerosis is a disease of the blood vessels involving inflammation and plaque build-up on artery walls (Madamanchi et al., 2005). Oxidization of lipoproteins, such as low-density lipoproteins, is thought to be an initiating factor of atherosclerosis and occurs when the antioxidant defence system of the body is not able to neutralize reactive oxygen species (Madamanchi et al., 2005; Sen, 1995). Oxidative stress can also damage DNA, particularly mitochondrial DNA (Madamanchi et al., 2005). Radicals can alter transcription factors leading to modification of gene and repair functions, which may result in DNA mutation (Madamanchi et al., 2005). The ability of increased oxidative stress to elicit diseases such as atherosclerosis reinforces the need for research into the area of reducing the negative impact of oxidative stress.

Exercise and oxidative stress

Exercise contributes to a healthy lifestyle, as it can help to maintain a healthy body weight and lower

blood pressure (Vuori, 2001) but it is also one of the factors that can elicit oxidative stress (Alessio et al., 2000; Bloomer et al., 2005; Clarkson & Thompson, 2000; Hudson et al., 2007). Current research suggests several pathways by which exercise can increase free radical production and subsequently induce oxidative stress (Alessio et al., 2000; Bloomer et al., 2005; Lachance et al., 2001). The primary pathway involves electron leakage from mitochondria during cellular respiration, especially during aerobic exercise, whereby there is an increase in oxygen flux, resulting in an increase in free radical production (Bloomer et al., 2005; Ji, 2001; Lachance et al., 2001; Mastaloudis, Traber, Carstensen, & Widrick, 2006). Exercise-associated physiological pathways such as those involved during muscle injury incorporating subsequent increased phagocytic activity, disruption to iron-containing proteins, and the production of xanthine oxidase can also result in increased oxidative stress (Bloomer & Goldfarb, 2004; Bloomer et al., 2005; Evans, 2000; Lachance et al., 2001). Furthermore auto-oxidation of catecholamines – sympathetic hormones released from the adrenal glands in greater quantities during exercise – can result in increased radical production (Cooper et al., 2002). Similarly, haem proteins such as oxyhaemoglobin and oxymyoglobin can undergo auto-oxidation as a result of exercise, thus inducing radical formation, especially that of superoxide (Cooper et al., 2002).

The influence of aerobic and anaerobic exercise on oxidative stress

It has been shown that aerobic and anaerobic exercise can elicit oxidative stress (Alessio et al., 2000; Bloomer & Goldfarb, 2004; Bloomer et al., 2005; Fisher-Wellman & Bloomer, 2009). Aerobic exercise can increase oxidative stress because there is an increase in oxygen demand by working skeletal muscles and thus possible electron leakage from the mitochondria during such exercise (Alessio et al., 2000; Bloomer et al., 2005; Fisher-Wellman & Bloomer, 2009). Electron leakage can in turn induce an increase in production of superoxide radicals and lipid peroxidation and thus a subsequent increase in oxidative stress (Bloomer and Goldfarb, 2004; Bloomer et al., 2005). In addition, there are a number of pathways through which anaerobic exercise can increase oxidative stress, such as xanthine and nicotinamide adenine dinucleotide phosphate-oxidase production, prostanoid metabolism, and ischaemia/reperfusion (Alessio et al., 2000; Bloomer & Goldfarb, 2004; Bloomer et al., 2005; Fisher-Wellman & Bloomer, 2009). Furthermore, the disruption to iron-containing proteins, increased phagocytic cell activity, and alteration of calcium

homeostasis that can be associated with this type of exercise can increase oxidative stress (Alessio et al., 2000; Bloomer & Goldfarb, 2004; Bloomer et al., 2005; Fisher-Wellman & Bloomer, 2009).

Physiological adaptations to oxidative stress

Low concentrations of radicals can result in physiological adaptations to exercise such as expression of antioxidant enzymes (e.g. superoxide dismutase and glutathione peroxidase) to reduce oxidative stress (Child et al., 1998; Gomez-Cabrera, Domenech, & Vina, 2008). Chevion et al. (2003) used trained soldiers to illustrate that marches of 50 and 80 km could elicit physiological adaptations such as an enhanced antioxidant status to reduce exercise-induced oxidative stress. Blood samples were taken at rest and post-march to determine antioxidant status and oxidative stress (Chevion et al., 2003). It was shown that markers of protein oxidation were reduced following the marches (Chevion et al., 2003). The authors suggested that internal mechanisms were activated by endurance exercise to remove oxidatively modified proteins and/or that antioxidant systems were better able to remove reactive oxygen species from the circulation (Chevion et al., 2003).

Classification of vegetarian diets

There are several categories of a vegetarian diet, with each category involving the exclusion of particular animal products. A lacto-ovo vegetarian diet excludes meat, fish, and poultry but permits the consumption of dairy and eggs (Venderley & Campbell, 2006). This category can be further subdivided into lacto vegetarians and ovo vegetarians, who exclude eggs or dairy respectively (Venderley & Campbell, 2006). A vegan diet excludes all animal products so that meat, poultry, fish, dairy products, eggs, gelatin, honey, and animal-derived additives and colours are not consumed (Venderley & Campbell, 2006). A macrobiotic diet includes fish but excludes meat, poultry, eggs, and dairy products as well as some non-animal products such as tropical fruit, processed sweeteners, and vegetables belonging to the nightshade family such as tomatoes and potatoes (Venderley & Campbell, 2006). A fruitarian diet is a modified version of the vegan diet and is primarily based on the consumption of raw or dried fruit, thus making it the least common of all vegetarian diets (Venderley & Campbell, 2006). The diversity of vegetarian diets suggests the need for research to quantify the proportion of the athletic and general population that follows such a diet and the possible health and performance benefits such a diet might provide.

Most literature investigating vegetarian athletes is dated (Abdulla et al., 1981; Millet, Guillard, Fuchs,

& Klepping, 1989; Nieman, 1988). More recently, Cox (2001) reported that up to 8.2% of athletes followed a vegetarian diet while 2.4% of American adults and up to 4% of Canadian adults reported that they were vegetarians (Venderley & Campbell, 2006). In the Australian 1995 National Nutrition Survey, up to 5% of adolescent girls, 6.2% of 19- to 24-year-old women, and 5.2% of 25- to 44-year-old women followed the lacto-ovo vegetarian diet (Ball & Bartlett, 1999). Australian data collected between 1996 and 2000 reported that 3% of the population consumed a vegetarian diet and up to 10% of Australians consciously excluded red meat from their diet at that time (Baines, Powers, & Brown, 2007). Current health and social concerns such as health benefits, environmental concerns, and animal rights issues may result in an increased proportion of Australians consuming a vegetarian diet if a more recent survey of dietary habits were conducted (Fox & Ward, 2008). The lack of current national data on the prevalence of vegetarian diets among Australians suggests this is an appropriate area for further research.

Health aspects of a vegetarian diet

A balanced vegetarian diet can reduce the risk of developing disease pathologies such as cardiovascular disease, obesity, type 2 diabetes, hypertension, and some cancers such as those of the prostate and colon (Barr & Rideout, 2004; Venderley & Campbell, 2006). Athletes and non-athletic individuals can benefit from a vegetarian diet, as such diets are rich in complex carbohydrates, fibre, fruit, vegetables, and antioxidants (Cox, 2001; Venderley & Campbell, 2006). Research indicates that the typical daily intake of fruit and vegetables of a vegetarian is between 500 and 1200 g (Venderley & Campbell, 2006), which exceeds the recommended intake of two fruit and five vegetable servings a day (National Health and Medical Research Council, 2007). An increased fruit and vegetable intake may be a predictor for antioxidant status, which may in turn reduce oxidative stress (Venderley & Campbell, 2006). A well-structured vegetarian diet is rich in antioxidants such as vitamins C and E (Ball & Bartlett, 1999; Millet et al., 1989), which protect the body against the detrimental consequences of oxidative stress (Powers & Lennon, 1999). Exercise has been shown to increase oxidative stress (Alessio et al., 2000; Bloomer et al., 2005; Clarkson & Thompson, 2000; Hudson et al., 2007), thus it is possible that a vegetarian diet may benefit athletes by reducing exercise-induced oxidative stress.

A well-planned vegetarian diet can adequately meet the nutritional needs of athletes (Cox, 2001) and the improved antioxidant status of vegetarians is

reported to be a predictor of reduced exercise-induced oxidative stress (Rauma & Mykkanen, 2000; Rauma et al., 1995). Thus studies considering the antioxidant status of different vegetarian diets would be of interest. Vegetarians have been shown to consume more fibre than omnivores probably due to their higher consumption of fruit and vegetables (Abdulla et al., 1981; Ball & Bartlett, 1999). The fibre content of a vegetarian diet may be a predictor of antioxidant status, as high-fibre foods, such as wholegrains, fruits, and vegetables are rich in antioxidant vitamins and minerals (Slavin, 2003). To date, the literature linking fibre intake with antioxidant status is unexplored.

Low-fat diets, especially those low in saturated fats, are beneficial to health status as they can reduce the risk of developing potentially fatal diseases such as cardiovascular disease (Oh, Hu, Manson, Stampfer, & Willett, 2005). A vegetarian diet has been shown to be low in saturated fats, with an emphasis on polyunsaturated and omega 6 fatty acids, which play a role in reducing cholesterol (Krajcovicova-Kudlackova et al., 1996) and vegetarians have been shown to have reduced serum cholesterol and triglyceride concentrations (Krajcovicova-Kudlackova et al., 1996; Szeto et al., 2004). A well-designed vegetarian diet is low in fat, high in fibre, and contains a variety of plant-derived antioxidants, which may play a role in reducing the risk of developing a number of chronic diseases such as cardiovascular disease.

Oxidative stress status of vegetarians

Vegetarians have higher intakes of vitamin C, vitamin E, and beta-carotene than omnivores, suggesting that their antioxidant status may be higher (Szeto et al., 2004; Venderley & Campbell, 2006). Vitamin C intake has consistently been shown to be higher among vegetarians (Millet et al., 1989; Rauma et al., 1995; Szeto et al., 2004), while there are conflicting data for vitamin E intake, with some studies suggesting vegetarians have a higher intake (Krajcovicova-Kudlackova et al., 1996; Rauma et al., 1995) while others indicate there are no significant differences between vegetarian and omnivore diets (Szeto et al., 2004). Vitamin E has been shown to function as both an antioxidant and a pro-oxidant depending on the level of oxidative stress (Rietjens et al., 2002). Thus, while vitamin E intake may be higher for vegetarians than for omnivores, it may also act as a pro-oxidant and consequently mediate adverse health conditions. Vegans were found to have a higher antioxidant status than omnivore controls when assessed by both dietary data and blood samples (Rauma et al., 1995). The vegan participants had higher blood concentrations of

vitamins C, E, beta-carotene, and antioxidant enzymes than the omnivore participants (Rauma et al., 1995). However, the vegan participants consumed a raw food diet, thus the results of Rauma et al. (1995) should be interpreted with caution as not all vegans and vegetarians consume exclusively raw foods. The raw nature of the food may have better preserved the antioxidant content of the food, providing an unequal comparison with the diet of the omnivore controls (Ismail, Marjan, & Foong, 2004). Szeto et al. (2004) showed that although the vegetarian participants consumed significantly more vitamin C and it made a greater contribution to antioxidant status, overall antioxidant status was not significantly better in vegetarians than in omnivores.

There appears to be insufficient literature addressing the oxidative stress and antioxidant status of vegetarians compared with omnivores in response to exercise. The literature available presents conflicting results regarding antioxidant status of vegetarians compared with omnivores at rest and it could be suggested that consumption of variations of vegetarian diets contributed to inconsistencies reported by Rauma et al. (1995) and Szeto et al. (2004). While analyses of vegetarian and omnivore diets demonstrate that antioxidant intake is consistently higher in vegetarian diets, which may lead to a superior antioxidant status, further studies are required to confirm this. Furthermore, the limited literature exploring the impact of vegetarian diets on exercise-induced oxidative stress suggests a need for studies to utilize techniques such as electron spin resonance spectroscopy, high-performance liquid chromatography or free radical analytical systems to investigate the possible relationship by quantifying markers of oxidative stress, such as plasma malondialdehyde and hydroperoxides.

Conclusion

In conclusion, there are limited studies investigating the antioxidant status of vegetarians and omnivores and the literature incorporating the effect of exercise is lacking. Oxidative stress, which can be increased during exercise, is associated with disease pathologies and vegetarians may have an enhanced antioxidant defence system to counter exercise-induced oxidative stress due to the increased quantities of fruit, vegetables, and wholegrains they consume. Conversion to a vegetarian diet is gathering pace in athletes due to the health benefits; however, research on the vegetarian athlete is lacking, thus it is important to determine the relationship between exercise-induced oxidative stress and the vegetarian athlete. To date, the link relating a vegetarian diet to exercise-induced oxidative stress is inconclusive with much of the literature focusing on supplementations

rather than antioxidant-rich diets, such as a vegetarian diet. Inconsistencies in the literature surrounding vegetarian diets and antioxidant status may be due to the variation of vegetarian diets of the participants involved in the studies. Further research is required to assess the antioxidant status of vegetarians, and whether vegetarian athletes have an advantage in overcoming exercise-induced oxidative stress. Vegetarians who exercise regularly and consume a well-planned diet could have a reduced risk of developing disease such as type 2 diabetes, a superior antioxidant status, and be better able to reduce exercise-induced oxidative stress.

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