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THE EFFECTS OF STRENUOUS EXERCISE AND NUTRITION ON THE IMMUNE FUNCTIONS OF ELITE ATHLETES

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Abstract:
The intense activities carried out by athletes result in them undergoing acute and chronic stress and this in turn will suppress their immune system as well as increase their oxidative species generation. On top of that, these athletes has a tendency to consume less calories than what is needed and they also have a tendency to avoid consuming fats, and the latter action may affect their immune system and anti-oxidant mechanisms. The stress caused by the exercise is dependent upon how intense the exercise is and its duration, and it is relative to the athlete's maximum capacity. The depletion of glycogen in the muscles affects the performance of the exercise as well as increases the stress. However, the glycogen stores can be protected if there is an increase in fat oxidation (glycogen sparing). Athletes should have balanced diets whereby the total calories consumed is the same as that expended and the carbohydrates and fats that are utilized must be replenished. However, many athletes fail to meet these important basic criteria thus compromising their glycogen or fat stores, and do not consume sufficient essential fats and micronutrients which are required to maintain their intense exercise, immune competence and anti-oxidant defense. Over-training or malnourishment may result in an increased risk of infections. In some cases, the intake of micronutrient supplements may strengthen the immune system and make up for the deficiency of the essential nutrients. Any nutrient

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deficiencies in the athletes' diet must be compensated with nutritional supplements, but it must not be over compensated. If the above-mentioned rules are complied with and the training are properly regulated so that there is no overtraining, the immune system can be maintained at the optimal level and this in turn will reduce the risk of diseases.

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Keywords: immunity, nutrition, training, exercise, leukocytes

1. Introduction

Tough, prolonged and heavy exercise regimes are often linked to the lowered immune functions of cells. In addition to that, insufficient nutrition or malnutrition can compound the negative effects of heavy exertion on immuno-competence. Diet lacking in proteins and specific micronutrients are known to have caused immune dysfunctions. A diet that contains sufficient zinc, iron and vitamin A, E, B6 and B12 is vital for the body's immune system to function properly although excessive intake of specific micronutrients can weaken the immune system and have a negative effect on health. Excessive intake of fats has also been known to weaken the immune system. As such, in order to maintain proper immune functions, athletes must consume a well-balanced diet that is able to meet their energy requirements (Alexander et al, 1985). Any athlete that exercises when his body is in a carbohydrate-depleted state will have more stress hormones in their blood circulatory system and several of their immune function indices will indicate that the body is in distress. On the other hand, the consumption of 30 – 60 grams of carbohydrate h71 when a person is carrying out continuous intensive exercise reduces the rise of stress hormones like cortisol and also constrain the amount of immune depression that is induced by exercise. However, there is insufficient convincing evidence to show that the much touted "immune-boosting" supplements like vitamins with anti-oxidant properties, glutamine, probiotics, zinc and Echinacea can prevent exercise-induced immune impairment (Peters et al, 1993).

2. The immune function of athletes

The function of the immune system is to recognize, attack, destroy and protect the body from foreign elements in the body. Basically, the immune system can be split into two broad functions namely, innate (non-specific and natural) and acquired (specific and adaptive) immunity and both of the work together synergistically. Any attempt by a foreign infectious agent to trespass into the body will immediately activate the innate system. The body's "first line of defense" consists of three general mechanisms with a shared common goal of preventing micro-organisms from entering the body and they are: (1) physical or structural barriers (skin, the linings of the epithelia, mucosal secretions); (2) chemical barriers (the acidity or alkalinity of bodily fluids and soluble factors such as lysozymes and complement system); and (3) phagocytic cells (e.g. neutrophils and monocytes or macrophages). If the innate system fails, the resulting infection will activate the acquired system which will then aid in the recovery from the infection. The monocytes or macrophages will ingest and process the foreign micro-organism, and will then present it (antigens) to the lymphocytes. This is immediately followed by the clonal multiplication of T- and B- lymphocytes that have receptors that are able to recognize the antigen, thus producing specificity and "memory" which enables the immune system to mount a strengthened cell-mediated and humoral response as and when the body is re-infected by the same pathogen. The production of cytokines including interleukins, interferons and colony-stimulating factors are vital for the activation and regulation of the immune functions (Nieman et al, 1990). An important characteristic of the immune system is the involvement of several functionally different types of cells that enables many types of defense mechanisms. Therefore, to assess the status of the various immune functions would require a thorough methodological approach whereby the target is a wide spectrum of immune system parameters. However, at the moment there are no instruments that can predict the cumulative effects of the many tiny changes in the immune system's parameters of the body's resistance to infections (Mackinnon et al, 1993). An athlete's heavy training and competition schedule can impair the immunity of the athlete and result in an increase in susceptibility to infections, specifically upper respiratory tract infections (URTI) (Mackinnon et al, 1997). This particular exercise-induced dysfunction of the immune system appears to be mainly caused by the immuno-suppressive actions of stress hormones like cortisol and adrenaline. Nutritional deficiencies can also weaken the body's immune functions and there are ample evidences to link the prevalence or severity of many infections with specific nutritional deficiencies (Barrett et al, 2002).

However, there is also evidence to show that excessive ingestion of individual micronutrients (e.g. n-3 polyunsaturated fatty acids, iron, zinc, vitamins A and E) can weaken the immune function, thereby increasing the risk of infection. It is commonly known to most athletes that even infections that are considered to be medically harmless can cause a drop in the athlete's performance (Pedersen et al, 1998).

3. Avoiding nutrient deficiencies

The key to having an immune system that is effective is to ensure that you consume sufficient nutrients that are essential for triggering the body's immune system together with its interactions, differentiations or functional expressions. Malnutrition weakens the immune systems defenses against foreign pathogens resulting in an individual becoming more susceptible to infections. Some pathogens may affect an individual's nutritional status through the suppression of appetite, poor nutrient absorption, higher nutrient requirements and greater losses of endogenous nutrients (Beals et al, 1994).

It is a widely accepted fact that insufficient intake of proteins weakens the immunity of the host as it harms the T-cell system and leads to an increase of opportunistic infections (Beals et al, 1994). The fact that protein deficiency weakens immunity is not surprising because the immune system's defenses rely on rapid cell replication and the production of proteins like immunoglobulins, cytokines and acute phase proteins. In humans, protein-cum-energy malnutrition leads to the deficiency of mature and fully differentiated T-lymphocytes as well as in vitro proliferative response to mitogens, although the second effect is reversible with nutritional repletion (Bassit et al, 2002). In addition to that, in a situation where there is protein-cum-energy malnutrition the T-lymphocytes CD4+/CD8+ (helper/suppressor cells) ratio is significantly decreased and the phagocytic cell functions, production of cytokines and complement formation are all reduced. Basically, protein-cum-energy malnutrition in humans affects all forms of human immunity and the severity is dependent upon the protein deficiency in relation to the energy intake. It is unlikely for athletes to suffer from extreme malnutrition unless his dieting is very severe, but some impairment to the defense mechanism has been seen in cases whereby the protein deficiency is moderate (Bishop et al, 1999).

Among the athletes, the individuals that are exposed to the highest risk of protein deficiency are those that are on weight-loss programs, vegetarians and having unbalanced diets (e.g. consuming carbohydrates that are disproportionately higher than their total protein intake). Generally, protein and energy deficiencies are accompanied by micronutrient deficiencies. Energy-restricted or low carbohydrate diets are commonly found in sports where being lean or having a low body mass is associated with having a performance or aesthetic advantage (e.g. endurance running, figure skating or gymnastics) or is necessary so as to fall within certain body weight criteria (e.g. boxing and weightlifting). Subsequently, this has led to the discovery of anorexia athletica, a new subclinical eating disorder and it is linked to an increase in susceptibility to infection. It has been found that even short-term dieting has an influence on the immune system in athletes, for e.g. a loss of 2 kg of body weight over a period of 2 weeks has an adverse effect on macrophage phagocytic functions (Nieman, 1997).

Moreover, for the immune system to function normally certain vitamins must be available. Any deficiency of fat-soluble vitamins like vitamin A and E as well as water-soluble vitamins like vitamin B6, B12, C and folic acid can harm the body's immune functions and reduce its resistance to infections (Bishop et al, 2001). If the vitamin deficiencies are corrected (through the intake of vitamin supplements), the body's immune functions will return to normal (Peters, 1996). In addition to that, some minerals are able to modulate the effects of the immune functions and it includes copper, iron, magnesium, manganese, selenium and zinc, but other than zinc and iron, the isolated deficiencies are very infrequent. Field studies have regularly shown that iron deficiency is associated with higher morbidity from infectious diseases (Pedersen et al, 2003). It has been shown that exercise has a noticeable effect on the metabolism of iron and zinc and as such, the requirements of such minerals are definitely higher in athletes as compared to individuals who lead a sedentary live because a lot of the minerals are excreted through sweat and urine. On the other hand, having too much minerals, like iron and zinc, can harm the body's immune system and the person can become more susceptible to infections (Coutsoudis et al, 1992). As such, supplements should only be taken as and when it is required and it is good to monitor the iron (serum ferritin and hemoglobin) and zinc status (erythrocyte zinc). Research on the intake of zinc as a supplement to treat common cold has been carried out in not less than 11 studies and the results of the studies have been published since 1984.

The results of the studies have been vague or unclear and the latest reviews of the matter are of the opinion that more research in the field must be carried out before zinc supplements can be recommended as a treatment for the common cold. There is not much evidence to show that zinc supplements can actually reduce incidences of URTI, but the available studies have indicated that for zinc to have any beneficial effect in treating the common cold (i.e. a reduction of the symptom's duration and/or severity) it must be ingested within 24 hours of the appearance of the common cold symptoms. The potential side effects of zinc supplements include nausea, reduction of high-density lipoprotein, bad or different taste, the decline of some immune cell functions (e.g. neutrophil oxidative burst) and distortion of the absorption rate of copper (Pedersen et al, 1989).

3.1 Eating the right food and types of fat

Comparatively, not much is known of dietary fatty acids role in the regulation of exercise-induced alteration of the body's immune functions. Two types of polyunsaturated fatty acids (PUFA), namely the omega-6 and omega-3 series (both are derived from linoleic acid), are essential to the body but they cannot be synthesized by the body and hence has to be derived from the diet. Reports show that diets having either omega-3 or omega-6 can alleviate the conditions of patients suffering from an over-active immune system like rheumatoid arthritis because the said two polyunsaturated fatty acids have anti-inflammatory effects (Gleeson et al, 2004). Some researchers advocate that high consumption of arachidonic acid as compared to the intake of fatty acids from the n-3 group may have undesirable effects on the inflammation and immune functions both during and after exercise (Eskola et al, 1978). But, a recent study has indicated that n-e PUFA supplementation does not have any influence on the exercised-induced increase of pro- or anti-inflammatory cytokines (Kinsella, 1987). There is a need to conduct further research on how the immune functions are affected after exercise or during heavy training sessions if the intake of essential fatty acids are altered. A recent study that examined the effects of a 7-week endurance training based on a carbohydrate-rich diet (65% of dietary energy are derived from carbohydrates) and fat-rich diet (62% of dietary energy are derived from fats) has indicated that the composition of the diet during the training period can influence the natural immunity because the carbohydrate-rich diet has increased natural killer (NK) cell activities as compared to that of the fat-rich diet. The conclusion that can be drawn from this research indicates that a fat-rich diet is harmful to immune functions as compared to that of a carbohydrate-rich diet; however, it could not ascertain whether the said effect is caused by insufficient dietary carbohydrate or a surplus of a specific dietary fat component (Toft et al, 2000).

3.2 The body's need for vitamins

A moderate increase in the intake of certain vitamins (like vitamins A and E) above the recommended amounts may improve the immune functions of very young or elderly persons (Venkatraman and David , 2002), but perhaps it does not have the same effect in young adults. However, the consumption of extremely large doses of specific vitamins, which is a fairly common practice amongst athletes, and damage the immune functions as well as having other toxic effects (Coutsoudis et al, 1992). For instance, a daily dosage of 300mg of vitamin E consume by men for a period of 3 weeks has resulted in significant depressed phagocytic functions and lymphocyte proliferation (Fogelholm, 2008). A recent study has shown that participants of an Ironman triathlon who took 600 mg of vitamin E daily for 2 months before the race have elevated oxidative stress as well as inflammatory cytokine responses during the race as compared to those given placebos for the same duration (Peake et al, 2007). Whereas elderly people (n = 652) who were on a daily dosage of 200 mg of vitamin E supplements had more severe infections which includes the total duration of the illness, fever as well as being restricted from carrying out physical activities. A recent study whereby patients with ischaemic heart disease that were given 600 mg per day of vitamin E had no effects on all-cause mortality or an increase in the number of deaths as compared to those that were given placebos. Mega dosages of vitamin A can damage the inflammatory responses and complement formation together with other pathological effects like an increased risk of foetal abnormalities in pregnant women (Gleeson et al, 2007).

Vitamins that have anti-oxidant properties such as vitamins A, C, E as well as beta-carotene (pro-vitamin A) may be required in larger amounts by athletes in order to deactivate the by-products of exercise-induced lipid peroxidation (Philipset et al, 2013). But, there are no conclusive data to show that nutritional anti-oxidants have any effect on muscle damage or a delayed onset of muscle tenderness. An increase in the production of oxygen free radicals caused by the spectacular increase in oxidative metabolism during exercise has the potential to inhibit immune responses (Nikolaidis et al, 2008).

4. Dietary manipulation to reduce the immune weaknesses

Elevated concentrations of stress hormones can caused exercise-induced immune functions and as such effective nutritional strategies can lessen the stress hormone response to exercise should be implemented so as to control the severity of exercise-induced immune dysfunction. There is definitely sufficient experimental evidence to back this notion, even though it is unclear whether the magnitude of such effects is enough to affect infection risk (Pedersen and Laurie, 2000).

4.1 Carbohydrate intake before and during exercise

In the last few years, a few research have studied how dietary carbohydrate affects hormonal and immune responses to exercise. These research (Mitchell et al, 1998) have discovered that if the individuals perform long-drawn-out exercises over a period of a few days when they have very low carbohydrate diets (usually 5 – 10% of their dietary energy intake are from carbohydrates), the level of the stress hormones (like adrenaline and cortisol) and cytokine (like IL-6, IL-1ra and IL-10) response is significantly higher than when they are subjected to normal or high carbohydrate diets. There are conjectures about athletes on insufficient carbohydrate diets putting themselves at risk from the acknowledged immunosuppressive effects of cortisol, as well as the repression of antibody production, natural killer cell cytotoxic activities and lymphocyte proliferation. It has been observed that when a person is exercising (1 h at 75% V O2 max) when he is in a glycogen-depleted state (caused by prior exercise and 2 days of low carbohydrate diet) his circulating lymphocyte numbers 2 hours after the exercise is much lower than when the same exercise was performed after 2 days of high carbohydrate diet. But, the management of the carbohydrate status did not have any effect on the reduction in mitogen-stimulated lymphocyte proliferation that occurred post-exercise (Nehlsen et al, 1997).

The ingestion of carbohydrates during exercise also reduces the increase in plasma catecholamines, adrenocorticotrophic hormone, cortisol, growth hormone and cytokines (Gleeson, 2007). Consuming carbohydrates during exercise also weakens the transferring of most leucocyte and lymphocyte subsets as well as the rise in the neutrophil (as the lymphocyte ratio blocks the exercise-induced drop in neutrophil function) and decreases the extent of the attenuation of mitogen-stimulated T-lymphocyte proliferation after prolonged exercise (Mitchell et al, 1998). In recent times, it has been shown that the consumption of 30 – 60 grams of carbohydrate h71 when cycling strenuously for 2.5 hours prevented the fall in the number and percentage of interferon-g-positive T-lymphocytes and suppressed interferon-g production from stimulated T-lymphocytes in placebo control trials (Henson et al, 1999). The production of interferon is important for the anti-viral defense and researchers have opined that the repression of interferon-g production can lead to an elevated risk of infection after prolonged exercise sessions (Hemmi et al, 2002).

Although carbohydrate intake during exercise is apparently effective in the minimization of some of the immune disquiets associated with lengthy continuous and strenuous exercise, it seems to be less effective for lighter intermittent exercises, like in football or rowing training sessions (Gleeson, 2013). It is also obvious that carbohydrate feeding is less effective in the reduction of immune cell trafficking and functional depression in situations whereby continuous extended exercise is performed until the person is fatigued. The ingestion of carbohydrates before the exercise does not appear to be very effective in controlling exercise-induced leukocytosis or depression of exercise, nourishment and immune neutrophil function (Gunzer et al, 2012). Currently, there is no evidence to show that the useful effect of ingesting carbohydrates on immune responses to exercise gives rise to lower incidences of URTI after extended exercise such as marathon races. Although carbohydrate ingestion has been shown to have beneficial effect on post-race URTI in a study of 98 marathon runners, the study sample is statistically insignificant and bigger-scale studies must be carried out to investigate this possibility (Gleeson et al, 2001).

4.2 Fluid intake during exercise

The intake of beverages when exercising not only prevents dehydration (which is linked to an increase in stress hormone response) for it also helps to sustain the saliva flow rate when the person is exercising. The contents of saliva includes several types of proteins with anti-microbial properties such as immunoglobulin-A (IgA), a-amylase and lysozyme. The secretion of saliva normally falls during exercise and regular intake of fluids during exercise has been found to prevent this effect and this has been confirmed by a recent study that shows regular intake of lemon-flavored drinks containing carbohydrates help to maintain saliva flow rate and this means that saliva IgA secretion rate is maintained during prolonged exercise as compared to a restricted fluid intake regimen (Bishop et al, 2000).

5. Dietary immunostimulants

Beta-carotene (pro-vitamin A) is both an anti-oxidant and an immunostimulant, and it has been shown to increase the number of T-helper cells in healthy humans as well as stimulate natural killer cell activity when it was added to in vitro human lymphatic cultures (Chew and Jean, 2004). Furthermore, it has been reported that elderly men that have been taking beta-carotene supplements at a dosage of 50 mg on alternate days for about 10 to 12 years have significantly higher natural killer cell activity when compared to another group of elderly men that were consuming placebos. But, the consumption of beta-carotene supplements by runners did not have any significant effect on the incidences of URTI after they have completed a 90 km ultra-marathon. In addition to that, smokers are advised not to consume more than 7 mg of supplements a day because there is a possible increase in risk of lung cancer in this group of people (Northoff et al, 1998).

Some herbal preparations are known to have immunostimulatory effects and many athletes are consuming products that contain Echinacea purpurea. But, not many controlled studies have been carried out to examine how dietary immunostimulants affect the exercise-induced changes in the immune system. A recent double-blind placebo-controlled study was carried out to study the effect of a pre-treatment daily dose of Echinacea purpurea juice on 42 triathletes 28 days before a race. A sub-group of athletes, treated with, was used as a reference and the participants were supplied with a micronutrient supplement that is vital for optimal muscular functions. The most striking finding during the said pre-treatment period was that not a single athlete from the E. purpurea group fell ill as compared to 3 and 4 individuals from the magnesium and placebo group respectively. It appears that pre-treatment with E. purpurea reduces the release of soluble IL-2 receptors both before and after the race and there was an increase in the exercise-induced increase in IL-6 (Northoff et al, 1998).

Several experiments have shown that E. purpurea extracts truly shows that there are significant immunomodulatory activities. Amongst some of the pharmacological properties that have been reported is that there is convincing evidence to support macrophage activation (Haddad et al, 2005). Phagocytotic indices as well as macrophage-derived cytokine concentrations were shown to be Echinacea-responsive in many assays and there were sufficient evidence to indicate that polymorphonuclear leucocytes and natural killer cells were activated. There were also changes in the numbers as well as activities of T- and B-lymphocytes, but its certainty is less. In spite of cellular evidence of immunostimulation, the description of the pathways that lead to enhanced resistance to infectious diseases are inadequate. Many dozens of experiments carried out on humans, including a few blind randomized ones, have shown health benefits, and the strongest data are from trials using E. purpurea extracts to treat acute URTI. Even though the trials indicate that there are modest benefits, but the said trials had limitation in both size and methodological quality. However, a recent randomized double-blind placebo-controlled study whereby unrefined Echinacea were administered at the onset of URTI to 148 college students did not show and obvious benefit or harm as compared to those given placebos (Barrett et al, 2002). Therefore, although there are a lot of reasonably good quality scientific data on Echinacea, its efficacy in the treatment of illness or the enhancement of human health has not been proven beyond a reasonable doubt. There is now a fairly large body of evidence to show that if probiotics, a food supplement that has "friendly" gut bacteria, is consumed regularly it can change the population of the micro-flora in the gut and affect changes in the immune functions of the gut. Studies have indicated that the intake of probiotic can improve the rate of recovery of patients suffering from rotavirus diarrhea, have better resistance to enteric pathogens as well as promote anti-tumor activities. That is also evidence to show that probiotics can alleviate some allergic and respiratory conditions in young children. However, as at this point in time there have not been a single published study on how effective the probiotics are when used by athletes (Isolauri et al, 2001).

6. Conclusions

1. Heavy exercise and nutrition have their own distinct influences on immune functions and the influences are stronger when the exercise stress and poor nutrition are acting synergistically.

2. Diets that are deficient in energy, protein and specific micronutrients are linked to weakened immune functions and higher susceptibility to infection. Sufficient consumption of iron, zinc and vitamins A, E, B6 and B12 are vital for the maintenance of the immune functions. Athletes are advised to always consume sufficient micronutrients.
3. To ensure that their immune functions are at an optimum level, athletes must eat a well-balanced diet that is sufficient to meet their energy demands. They should also make sure that they consume sufficient amounts of protein and micronutrients.
4. The following of energy-restricted diets to consume vitamin supplements.
5. Athletes that exercised in a carbohydrate-depleted state will have bigger increases in circulating stress hormones as well as a greater perturbation of some immune function indices.
6. Persons performing extended exercises are advised to consume carbohydrates (30 – 60 grams h71) in their drinks as it can weaken some of the immunosuppressive effects of prolonged exercise. However, there is no evidence to support this assertion.
7. It is not advisable to consume mega-doses of vitamins and mineral because the excessive intake of some micronutrients (iron, zinc, vitamin E) can harm the body's immune functions.
8. Fat-rich diets can suppress some features of the immune cell function.
9. There are insufficient evidence to support the so-called 'immune-boosting' supplements like high dosages of anti-oxidant vitamins, glutamine, probiotics, zinc and Echinace that is supposed to prevent exercise-induced immune impairment. Current available evidence on the efficacy of Echinacea extracts, probiotics and zinc lozenges in the prevention or treatment of common infections is scarce and as such, there is no recommendation on the use of these supplements.
10. It is arguable whether antioxidant supplements are required or desirable for athletes. Evidence of the effects of high dosages of vitamin C in the reduction of post-exercise incidences of URTI are conflicting and there is no evidence to show that this practice can actually prevent exercise-induced immune impairment.

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