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Effectiveness of Probiotics Supplementation in Improving Health Conditions of Athlete Groups

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Abstract:

The gut microbiota, comprising bacteria, fungi, archaea, and viruses, plays a critical role in regulating various physiological functions in healthy adults. In athletes, strenuous physical exercise can lead to gut dysbiosis due to oxidative stress, immune suppression, and metabolic imbalance. This paper describes the effects of immunosuppression, oxidative stress and energy metabolism induced by high intensity exercise and training on the health of athlete populations. The gut microbiota is suggested to be associated with these responses. The role of probiotics in improving the gut microbiota is being recognised. Specific details of the improvement of overall health and maintenance of the stabilised gastrointestinal microbiota in athlete population through the influence of probiotic interventions on immune responses, oxidative stress and energy metabolism aspects are discussed in this paper. The positive effects of probiotic interventions in improving the health of athletic populations are suggested, but future research will be needed to determine the specific effects on sports performance.

Keywords: Probiotics supplementation, gastrointestinal microbiota, immune response, oxidative stress, energy metabolism.

1. Introduction

The gut microbiota of healthy adults is composed of bacteria, fungi, archaea and viruses colonizing the surface of the gut [1]. The major gut microbiota is characterized by the Firmicutes, Bacteroidetes, Actinobacteria, and Aspergillus [1,2]. The gut microbiota is regulated through differing environmental factors including diet, stress and physical activity, which contribute to the alteration and imbalance of the gut microbiota [3] Among sports populations, training fatigue associated with strenuous physical exercise promotes the increased risk of developing issues including immunosuppression, oxidative stress, and energy metabolism [4]. Oxidative stress, electrolyte imbalance, and glycogen depletion through intensive training like endurance exercise modifies the gut microbiota [1,5]. Additionally, the ability of gut mi-

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crobiota to regulate the immune system, improve gastrointestinal health and ameliorate post-exercise inflammatory responses also contributes to the bi-directional effects on the physical activities of individuals [1,6].

Probiotics have been suggested as being effective in restoring normal gut microbiota and improving host health according to current research results on gut microbiota and the diseases resulting from gut dysbiosis [7]. Specifically, the benefits of probiotics have been identified as strengthening the immune system, improving gastrointestinal symptoms, and preventing disease [7]. Current research suggests the strains that are commonly used in probiotic blends include the genera of Lactobacillus, Streptococcus, Bifidobacterium, and Clostridium [7]. Considering the positive benefits of probiotics in improving gastrointestinal dysbiosis and diseases, probiotics have been used extensively to reduce inflammatory responses and associated disease issues including gastroenteritis in athletes for improvement of their health [1]. The results from the current research conducted on mice demonstrated a significant 13% improvement in endurance performance in running duration with the administration of strains of Veillonella [8]. This promising finding supports the positive effects of probiotic encapsulated by specific strains of probiotics in increasing the diversity and abundance of the gut microbiota in athletes to improve the overall athletic performance. Furthermore, the high fibre and probiotic diet significantly reduced the recovery time of athletes after high intensity training and improved gastrointestinal dysbiosis related disease contributing to enhanced athletic performance [9,10].

Therefore, the main aim of this paper is to investigate the effectiveness and detailed effects of probiotics for the several perspectives including the improvement of oxidative stress, immune system, gastrointestinal disorder, and energy metabolism in athletic groups, which consequently will provide the comprehensive report on the potential benefits of probiotics in improving the health of athletes and enhancing athletic performance.

2. Probiotics and Athletes Health

2.1 Oxidative Stress

Oxidative stress is defined as an imbalance between the accumulation of reactive oxygen species (ROS) produced as the by-product of enzymatic reactions and the detoxication of biological systems to repair systemic damage [11]. ROS and other oxidative products have been implicated in the impairment of essential cellular functions. The high intensity of physical activity has been associated with different physiological changes including increased oxidation of glucose, oxidation of fatty acids, increased production of ROS and oxidative phosphorylation [12]. The exercise induced oxidative stress is influenced by several significant factors including exercise duration, intensity and nutritional intake [12]. Specifically, the activity of antioxidant enzymes (superoxide dismutase SOD, glutathione peroxidase GPx, etc.) is decayed with the accumulation of chronic fatigue during exercise with high intensity, which contributes to the imbalance between oxidative defence and oxidative stress [13]. Research results have demonstrated that the composition of the gut microbiota is associated with the individual redox balance, reporting that Lactobacillus and Bifidobacterium were negatively associated with oxidative status [13]. Specifically, The oxidative stress induced by early weaning stress was identified in this randomised controlled animal experiment which significantly reduced the proliferation of Bifidobacterium and Lactobacillus and increased SOD levels in the gastrointestinal tract [14]. In another experiment conducted on mice, the higher levels of Bacteroides in the gut microbiota were associated with protective effects towards pro-oxidative and pro-inflammatory responses induced by intestinal infections [15]. These evidences demonstrate the positive benefits of the gut microbiota in regulating the activity of antioxidant enzymes.

The gastrointestinal probiotics perform diverse effects on antioxidants, for instance through the release of antioxidant molecules and antioxidant enzymes interacting directly to the removal of ROS [12]. Additionally, probiotics have been suggested to be associated with the reduction of the activity of enzymatic reaction systems involved in the production of ROS [12]. Specifically, probiotics improve the antioxidant system to regulate the redox status of the individual through its ability of regulating antioxidant system, ROS-producing enzymes and gut microbiota etc [12]. The antioxidant enzyme SOD generates the most abundant types of ROS (superoxide) and is considered as the core regulator of ROS levels [16]. The research results demonstrated that Lactobacillus casei BL23 was associated with increased intestinal enzymatic activity, which decreased the level of intestinal inflammation in mice with Crohn‘s disease [16]. Furthermore, the combination of Lactobacillus acidophilus La5 and Bifidobacterium lactis Bb12 was associated with increased erythrocyte SOD and GPx activity with improved overall antioxidant activity, demonstrating the effects of probiotics in improving individual antioxidative system [16].

ROS-producing enzymes includes NADPH oxidase (NOX), cyclooxygenase (COX) and CYP. The NOX complex is also the major source of ROS production. Research results in rats indicated that combined probiotic treatment including Lactobacillus fermentum CECT5716, Lactobacillus coryniformis CECT5711 and Lactobacillus gasseri CECT5714 reduced NOX activity and improved oxidative stress in rats [16]. Also, the COX produces ROS through the enzymatic reaction. Research results identified that Lactobacillus acidophilus reduced the expression of COX-2 in catla thymus macrophages [16]. The poor coupling of the cytochrome P450 (CYP) contributes to continuous production of ROS which affects cellular function. Research results reported that reduced intestinal CYP1A1 enzymes level were observed in rats after receiving Lactobacillus casei, suggesting the effectiveness of probiotics in controlling ROS levels [16].

Lactic acid, acetic acid and propionic acid produced by Lactobacillus and Bifidobacterium decreased intestinal pH and inhibited the growth of pathogenic bacteria, maintaining gut microbiota balance and reducing oxidative stress levels [16]. Results of randomised controlled trials in athletic populations have indicated that the combined supplements of probiotic with Lactobacillus paracasei IMC502 and Lactobacillus rhamnosus IMC501 was associated with increased antioxidant levels, which resulted in the neutralisation of ROS and the reduction of oxidative stress [12]. However, another randomised controlled trial demonstrated that additional intake of probiotic supplementation (Lactobacillus) was not associated with SOD activity [12]. Furthermore, the research results regarding the effect of probiotic supplementation on the change in oxidation, intestinal barrier markers and inflammation suggested that additional probiotic supplementation only decreased barrier markers in faeces resulting in increased intestinal permeability, but was not associated with improved oxidation and inflammation [12]. Therefore, the application of probiotics addressing the oxidative stress induced by exercise to reduce intra-individual ROS has the potential in improving overall health, which require the future research to determine the effectiveness of probiotics supplementation in improving performance among athletes group.

2.2 Immune System

Immune responses are suppressed during exercise in the form of total leukocyte counts, serum immunoglobulin levels, lymphocyte, granulocyte and total T-cell counts among other immune response [13]. The sustained high intensity exercise is accompanied by elevated plasma cortisol levels contributing to the efflux of bone marrow neutrophils and other leukocyte subpopulations [13]. Vigorous exercise is distinct from fitness and habitual moderate exercise by its promotion of increased levels of different pro-inflammatory cytokines (interleukin 1 (IL-1), Tumour necrosis factor (TNF) receptor and macrophage inflammatory protein-1 etc.), suggesting the dose-response effect between the biological response and the immune response [13]. The current research results suggest the divergent outcomes for intense exercise and immunoglobulin A (IgA) levels. Specifically, in mice research, it was observed that intensively exercising mice were associated with increased levels of IgA encapsulating bacteria which maintains the tolerance and non-inflammatory host-microbe relationships, suggesting an increased resistance to intestinal pathogen infections in the mice [13]. However, research results from a 50-week trial of elite rowing athletes identified significant negative correlations between high-intensity training and competition and IgA levels, suggesting the concept of "open window" defined as the period after high-intensity exercise resulting in impaired immune function that is associated with greater risk of clinical infection by viruses and bacteria [17]. Additionally, the increased prevalence of digestive disorders is considered to be associated with the physiological and psychological stress, dietary deficiencies and sleep disorders induced by the intensive exercise, resulting in symptoms of abdominal pain or diarrhoea [13]. Training-induced immune response variation decreases the GI tract blood flow, nutrient content and oxygen consumption which increases gastrointestinal permeability and impaired intestinal mucosa [13]. These risk factors consequently contribute to the development of an inflammatory immune response, resulting in symptoms of leaky gut related to endotoxemia [13].

As mentioned above, probiotics have been proven as beneficial in improving intestinal health. The protective role of probiotics in modulating the immune system has been suggested as well. Specifically, in a randomised controlled trial including 56 marathon runners, daily consumption of 80g of fermented milk containing 40x10^9 live cells of Lactobacillus casei Shirota (LcS) demonstrated the ability to maintain levels of Secretory Immunoglobulin A (SIgA) and provided post-exercise immunoprotection, suggesting the protective effects of LcS on the athlete population against pathogenic infections after exercise [18]. Additionally, this research identified that daily intake of LcS reduced the levels of pro-inflammatory cytokines (IL-6, IL-10, IL-13 and TNF-α, among others) [18]. Among them, IL-6 and IL-10 are implicated in the Th2 immune response. Increased plasma IL-6 levels during and after exhaustive exercise respond to exercise-induced reduced muscle glycogen and skeletal muscle fibre contraction [18]. The high levels of myokine have been suggested to correlate with the induction of the Th2 immune response. These cytokines recruit and activate eosinophils, which contribute to the continuation of the Th2 immune response [18]. Thus, these evidences suggest that LcS consumption

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reduces individual immune responses by lowering pro-inflammatory cytokines and thus reduces the risk of pathogenic infections in the athlete population resulting from the open-window period.

2.3 Energy Metabolism

Energy availability has been suggested to be the important constraining factor during exercise. Fermentation of dietary carbohydrate intake in the gut promotes the core activities of the gut microbiota including colonic carbon and energy metabolism [13]. Plant-derived polysaccharides are digested and fermented in the GI tract into short-chain fatty acids (SCFAs), which consequently function as energy sources via bacteria including reductive acetogen and sulphate-reducing bacteria, etc. [13]. SCFAs impart influences on the composition of the gut microbiota, permeability, intestinal motility, and proliferation of epithelial cells through mechanisms influencing energy utilisation and pH control [13]. Additionally, the diets of athletic populations differ according to requirements requiring their diets based on high protein and carbohydrates, low fat, and key micronutrient intake [13]. The review results indicated that, besides SCFAs produced by the fermentation of amino acids from protein breakdown, ammonia, phenols and compounds composed of amines and hydrogen sulphide increased intestinal permeability and subsequently increased risk of leaky gut and inflammation [13]. As aforementioned, improving the gut microbiota and the fermentative capacity through the application of probiotics would limit the occurrence of diseases caused by toxic metabolites produced by protein decomposition.

Probiotics reinforce intestinal barrier function by inducing tight junction protein synthesis and assembly [19]. Disrupted tight junctions release lipopolysaccharides (LPS) which regulate the activity of monocytes and macrophages, increasing the levels of pro-inflammatory factors within the individual [19]. Gastrointestinal dysbiosis resulting from endurance exercise also contributed to CHO malabsorption, limiting endurance performance in athletic populations [19]. The research results demonstrated that the four-week probiotic intake intervention increased CHO oxidation and absorption rates, suggesting the potential effect of probiotic intake in improving endurance exercise performance through elevating CHO absorption and oxidation rates in athletic populations [19].

SCFAs have been suggested to have significant benefits for energy metabolism for mammals.(20) Moreover, activation of fatty acid receptor 2 (FFA2) and fatty acid receptor 3 (FFA3) of SCFAs promotes intestinal GLP-1 secretion to increase glucose uptake, and gut PYY secretion to decrease gut motility and to increase nutrient absorption respectively [19]. Probiotic consumption promotes fermentation of undigested CHO in the GI tract producing SCFAs resulting in beneficial effects on the host [19]. Additionally, diseases caused by gastrointestinal dysbiosis including inflammatory bowel disease (IBD) are associated with the imbalance of the gut microbiota and reduction of the metabolite of SCFAs [20]. Butyrate from SCFAs promotes mitochondrial respiration that mitochondria functions as the producing centre of adenosine triphosphate (ATP) [20]. The activation of AMPK in liver, muscle and adipose tissue from butyrate and acetate contributes to energy metabolism benefits such as glucose uptake [20]. The Lactobacillus rhamnosus strain GG (LGG) as the most widely used probiotic in animal research were identified to be associated with the significant production of propionate of SCFAs.(20) These evidences suggest the feasibility of probiotics consumption in positively affecting the SCFAs production as novel approach to promote health of athletes group.

2.4 Other Exercise Induced Symptoms

The benefits of probiotic supplementation for the well-being of the human gastrointestinal tract have been demonstrated, and further existing research has focused on the improvement of probiotics on other health conditions in the athlete population [13]. The review results demonstrated that additional probiotic yoghurt supplementation with Lactobacillus acidophilus spp., Lactobacillus delbrueckii bulgaricus, Streptococcus salivarius thermophilus and Bifidobacterium bifidum was associated with decreased frequency of upper respiratory tract infections (URTIs) and shorter duration of symptoms after competition in the endurance swimmers [13].In addition, this additional supplementation significantly improved the maximum oxygen uptake of the athletes which was explained by the reduced prevalence of URTI [13]. Additional supplementation with Lactobacillus fermentum VRI-003 was identified to enhance the mucosal immune system of the upper respiratory tract and reported reduced upper respiratory tract infections with less severe symptoms in the research study with long distance runners.(13) Decreased levels of SIgA after high intensity exercise result in increased risk of upper respiratory tract infections [18]. Elaborately, the research results demonstrated that athletes who were supplemented with LcS exhibited higher SIgA levels after the marathon compared to the placebo group, but higher SIgA levels were not observed among the LcS group [18]. Moreover, mucosal immune agents for instance antimicrobial peptides affected mucosal immunity predominantly. The research results observed that high intensity post-exercise was associated with significantly lower salivary lysozyme levels, but athletes consuming LcS performed no reduction, demonstrating the positive impact of probiotic supplementation on mucosal immunity in the upper respiratory tract [18].

Additionally, in clinical research, additional probiotic supplementation was associated with significant reductions to fatigue time. In mice consumed with Lactobacillus plantarum TWK10 demonstrated significantly increased endurance swimming time, and increased number of slow-twitch muscle fibres in the gastrocnemius muscle [5]. In a randomised controlled trial of male runners with training history, the probiotic intake intervention with mixed strains was identified to significantly increase running time with 16% prolongation, but no differences in gastrointestinal permeability or gastrointestinal imbalance were observed in this research [21] However, improved exercise performance has been reported incompliance in other research results with different outcomes. In female swimmers, there was no observed effect on swimming performance after consuming the mixed probiotic yoghurt intervention [22]. Also, the probiotic intervention was also not associated with improvements in physical performance among marathon runners [23]. Therefore, in consideration of the individual differences between different athletes, larger randomised controlled trials would be required to be implemented to determine the enhanced sports performance by probiotic supplementation in the athlete population.

3. Conclusion

In conclusion, probiotic supplementation has been widely used to improve the stability of the microbiota of the gastrointestinal tract. The gut microbiota of athletic populations is affected by fatigue, immune response, oxidative stress and energy metabolism after exercise. Reactive oxygen species produced by enzymatic reactions impair cellular function. The accumulation of antioxidant enzymes produced after exercise results in the redox imbalance between oxidative defences and oxidative stress, which consequently affects the gastrointestinal microbiota. The administration of probiotics modulates the activity of antioxidant enzymes and improves the redox status, thus improving intestinal permeability and demonstrating the positive effect of probiotics in improving oxidative stress. Additionally, the open window period after high-intensity exercise and training is associated with lower levels of IgA and increased pro-inflammatory cytokines. The weakened immune response increases gastrointestinal disorders like lower abdominal pain, diarrhoea and leaky gut associated with endotoxaemia. Probiotic intake interventions maintain the SIgA levels and reduce the levels of pro-inflammatory cytokine in athletes, contributing to reduced risk of pathogenic infections. These results suggest that probiotic intake is effective in improving the disease risk of gastrointestinal dysbiosis and pathogenic infections associated induced from high-intensity exercise. Furthermore, probiotic intake increased energy availability and increased SCFAs produced through fermentation, which in turn maintained the stability of the gut microbiota. Meanwhile, probiotic intake enhances the intestinal barrier function and consequently increase intestinal CHO uptake, demonstrating the benefits of probiotics in energy metabolism for the host. Finally, the intervention of probiotic intake reduces the risk and severity of pathogenic infections in the upper respiratory tract of athletes and maintains mucosal immunity of the upper respiratory tract. Regarding the sport performance, the results of probiotic intake in mice demonstrate significant improvements in endurance performance but were not observed in the human trials. Therefore, these results suggest the effective benefits of probiotics in improving the overall health of athlete population, but future research results will be needed to determine the exact results regarding exercise performance ability.

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