European Journal of Sport Science
Publication details, including instructions for authors and subscription information: http://www.tandfonline.com/loi/tejs20

Probiotics supplementation for athletes - Clinical and physiological effects

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Published online: 23 Oct 2014.

European Journal of Sport Science, 2014
http://dx.doi.org/10.1080/17461391.2014.971879

ORIGINAL ARTICLE

Probiotics supplementation for athletes – Clinical and physiological effects

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Abstract
Probiotic supplementation has traditionally focused on gut health. However, in recent years, the clinical applications of probiotics have broadened to allergic, metabolic, inflammatory, gastrointestinal and respiratory conditions. Gastrointestinal health is important for regulating adaptation to exercise and physical activity. Symptoms such as nausea, bloating, cramping, pain, diarrhoea and bleeding occur in some athletes, particularly during prolonged exhaustive events. Several studies conducted since 2006 examining probiotic supplementation in athletes or highly active individuals indicate modest clinical benefits in terms of reduced frequency, severity and/or duration of respiratory and gastrointestinal illness. The likely mechanisms of action for probiotics include direct interaction with the gut microbiota, interaction with the mucosal immune system and immune signalling to a variety of organs and systems. Practical issues to consider include medical and dietary screening of athletes, sourcing of recommended probiotics and formulations, dose–response requirements for different probiotic strains, storage, handling and transport of supplements and timing of supplementation in relation to travel and competition.

Keywords: *Probiotics, supplements, gastrointestinal illness, respiratory illness*

Introduction

Probiotic supplementation is attracting attention of the sports community to promote good health, training and exercise performance. Probiotics consist of bacteria, especially lactic acid bacteria, and are available commercially in capsule form, as a powder or in selected dairy products such as fermented milk or yoghurt. Probiotics exhibit strain-specific differences in their ability to colonise the gastrointestinal tract, in clinical efficacy and in the type and magnitude of benefits to health in a range of population cohorts (Gleeson, 2013). However, investigation of the effects of probiotics in athletes has lagged behind both animal studies and investigation of various clinical conditions in the general community. A Medline search conducted in May 2014 yielded the following listings for various combinations of key terms (probiotic and athlete, n = 23; probiotic and rodent, n = 678; probiotic and child, n = 954; probiotic and elderly, n = 1191). Clearly, the focus of the research community has been investigating the beneficial effects of probiotics as a treatment for acute and chronic illnesses in various subgroups of the general population. The athlete and the coach, and their support personnel, are interested in maintaining good health and sporting performance (Carlson, 2010; Christensen et al., 2006).

Given the small number of studies that have examined the effects of probiotic supplementation in athletes and other highly active individuals, it is somewhat premature to issue definitive clinical and practical guidelines. To overcome the shortage of studies, clinicians and scientists working with athletes need to translate and apply findings of selected

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studies in closely related fields. Research areas including clinical immunology, nutritional immunology, nutrition, sports medicine and exercise physiology should yield useful insights (Pyne, West, & Cripps, 2013). It is often difficult to study athletes during training and competition, and a wide range of interactions between diet, physical activity and other lifestyle stresses needs to be considered. Management of training, lifestyle stresses and dietary practices is always a challenge in athletes leading busy lives with sporting, employment, family and travel commitments.

Athletes should place a high priority on good health to maintain sporting performance. The primary interest in probiotic supplementation has traditionally been around promotion of gut health, as mild illness may have detrimental impacts on competitive performance (Pyne, Hopkins, Batterham, Gleeson, & Fricker, 2005). The importance of the gut in digestion and provision of energy substrates for exercise and physical activity is well characterised in numerous sports nutrition studies. More recently, interest in the use of probiotics has focused on preventing respiratory illness, particularly the common cold. From an immunological perspective, the gut plays a primary role in mediating defence against infection and regulating mucosal homeostasis (Lefrançois & Puddington, 2006; Otczyk & Cripps, 2010). Host defence at mucosal surfaces lining both the respiratory (particularly the oropharynx) and gastrointestinal tracts protects individuals against common pathogens. However, during prolonged or intensive exercise, the mucosal surfaces may be disturbed, increasing the risk of common gut problems such as nausea, bloating, cramping, pain, diarrhoea or bleeding (de Oliveira & Burini, 2011). Managing dietary practices, including nutritional supplementation, could be useful in reducing the risk of common respiratory and gut issues impairing training and competition (Lamprecht & Frauwallner, 2012). In this commentary, we consider the background to probiotic supplementation and gut health in athletes, review the clinical and physiological outcomes of probiotic studies in athletes or highly active individuals and highlight some practical issues for effective use of probiotic supplements in the field.

Probiotics and immune modulation

Understanding the role of the microbiota in promoting and maintaining gut health and general wellbeing is increasing rapidly across various fields including clinical medicine, gastroenterology, endocrinology, immunology and nutrition (Maslowski & Mackay, 2011; Pyne et al., 2013). The mucosal lining of the gastrointestinal tract represents the first line of defence against invading pathogens and an important interface with the host immune system. A key element in the immune response is the capacity to differentiate between pathogenic (the so-called bad bacteria) and non-pathogenic (good bacteria) commensal microbes in the gastrointestinal tract (Strober, 2011). Animal and human studies indicate that the microbiota is central to health and disease, in particular the growth and maturation of the mucosal immune system, optimising immune responses and preventing unnecessary and aberrant inflammatory activity (Wallace et al., 2011). Medical research has established that various conditions such as obesity, metabolic syndrome and colitis are affected by the interaction of both host (e.g. genotype and age) and environmental factors (Binnendijk & Rijkers, 2013). Presumably, a similar interaction might also apply to common illnesses experienced by athletes.

The mucosal lining of the gut, genito-urinary tract and respiratory tract hosts a thriving bacterial community. The gut is the largest physiological compartment inhabited by bacteria (Brüls & Weissenbach, 2011). Nutrient load can exert substantial influence on the structure of the bacterial community (Jumpertz et al., 2011), indicating the importance of daily dietary practices and specific nutritional interventions around training and competition. Given the transit of probiotic supplements through the gastrointestinal tract and the potential interaction with underlying components of the immune system, it is not surprising that efforts to identify the mechanisms via which probiotics exert positive health effects have focused on immune modulation. As yet, there is little direct evidence of the ways in which athletes' dietary practices affect their microbiota. Given the energy requirements of different sports, management of body mass and the need for macronutrients to sustain performance or promote adaptation, profiling the microbiota in athletic cohorts may hold promise in reducing the risk of illness impairing training and competition.

Of the multiple potential mechanisms of action for probiotics (Table I), direct interaction with the gut microbiota, promotion of the integrity of the intestinal mucosa, interaction with the mucosal immune system and immune signalling to a variety of organs and systems including the liver, brain and respiratory tract have all received particular attention. A detailed treatment of mechanisms of action is beyond the scope of this review and interested readers are directed elsewhere (Binnendijk & Rijkers, 2013; Pyne et al., 2005; Statistics, 2013). In brief, probiotics appear to augment intestinal communication between the host immune system and commensal bacteria to establish mutualistic benefits. The putative roles of microbial-derived short-chain fatty acids – particularly butyric acid (colon) –are important in mucosal homeostasis through regulation of epithelial

Table I. Proposed mechanisms of action for enhancing immune function in the gastrointestinal and respiratory tract with probiotics

Proposed mechanisms	References
Enhanced epithelial cell barrier function	Lamprecht et al. (2012)
Modified macrophage/lymphocyte cytokine secretion	Clancy et al. (2006)
Antibacterial effects of colonisation	Strober (2011)
Upregulation of antimicrobial peptides and antioxidant compound/enzyme production	Martarelli et al. (2011)
Induction of regulatory T-cells	Liu et al. (2010)
Augmentation of communication between immune system and commensal microbiota	Otczyk and Cripps (2010), Lefrançois and Puddington (2006)
Involvement of short-chain fatty acids in Treg cell homeostasis	Geuking et al. (2013)

turnover and induction of regulatory T-cells (Treg cells; Geuking, McCoy, & Macpherson, 2013). Beyond the gastrointestinal tract, probiotics have an immunomodulatory effect through the common mucosal immune system, in which cells from inductive sites, such as Peyer's Patches in the intestines, traffic to mucosal surfaces following interaction with antigen-presenting cells (Statistics, 2013). In terms of a possible mechanism for probiotics and improved respiratory health, animal studies examining airway hyper-responsiveness indicate that Treg cells in the respiratory tract play an essential role in regulating mucosal immunology (Liu et al., 2010). An abnormal immune response could reflect an increased pro-inflammatory response to a bacterial component, a decreased immune regulatory response or a combination of the two (Strober, 2011). Probiotics are a potential nutritional strategy to correct these aberrant immune responses.

Probiotics and gut health

Gastrointestinal problems can occur in athletes participating in prolonged endurance events including cyclists, triathletes and marathon runners (Rehrer et al., 1992). Symptoms of nausea, cramping, bloating and diarrhoea most likely reflect redistribution of blood flow from the gut to the peripheral circulation for cooling purposes. Exercise-induced redistribution of blood can result in splanchnic hypoperfusion as a possible mechanism for gut dysfunction (van Wijck et al., 2011, 2012). The physical up-and-down movement of the gut during running could also explain an increase in the frequency of gut symptoms (Jeukendrup et al., 2000). Interactions between prolonged exercise, challenging environmental conditions and nutrient and fluid intake may also increase risk of gut problems (Jeukendrup, Jentjens, & Moseley, 2005). Probiotic supplementation in combination with other dietary strategies (e.g. consuming well-tolerated foods and drinks, avoiding spicy foods) could assist athletes with a history of gut problems.

To promote benefits to gut health, the issues of dose response and duration of supplementation must be addressed in both research and practical settings. A meta-analysis on probiotic efficacy for treating gastrointestinal illnesses indicated that dosages in the range of 10^6–10^{10} can exert beneficial effects (Pyne et al., 2005). Some commercial probiotic preparations have 10–25 billion colony forming units (CFU), with one study showing beneficial effects using a dose of 45 billion CFU (Shing et al., 2014). Other commercial preparations contain a smaller dose of probiotics often 10^9–10^{11} CFU. There is an emerging trend of manufacturers producing multi-strain probiotic preparations, sometimes in combination with prebiotics and/or other bioactive compounds. As little as seven days of supplementation is required to elicit substantial changes (colonisation) in the microbiota (Pyne et al., 2005). The long-term effects of probiotic administration in athletes over several months or years on gut health, immune function and rates of illness are unclear, as in most studies the supplementation period was only for 4–16 weeks.

Reviews of probiotic supplementation

A number of reviews of probiotic supplementation in the general population have been published in recent years. One review reported that over 700 randomised controlled studies using probiotics have been conducted in human subjects (Wallace et al., 2011). It appears there is sufficient evidence for using probiotics in the clinical prevention and treatment of various gastrointestinal tract disorders including gastroenteritis, diarrhoea and inflammatory disorders such as Crohn's disease (Gill & Prasad, 2008). It should be noted that evidence for probiotic health claims have been rejected by regulatory agencies due to limitations in clinical trial design and reporting (Binnendijk & Rijkers, 2013). The two most extensively studied probiotic species are *L. acidophilus* and lactic acid bacterium or *Bifidobacterium lactis*. A more targeted Cochrane review of probiotics and upper respiratory tract illness (URTI) analysed 10 controlled trial studies involving 3451 subjects (Hao, Lu, Dong, Huang, & Wu, 2011). The mean effect of probiotics was a ~40% reduction in the likelihood of an URTI episode, and ~30% reduction in the rate of medication usage (antibiotic prescription) for individuals experiencing an acute URTI. However, there was considerable imprecision around these estimates and further investigation was suggested. The most recent authoritative systematic review (King, Glanville, Sanders, Fitzgerald, & Varley, 2014) concluded that significantly fewer numbers of days of illness per person, shorter illness episodes by almost a day without an increase in the number of illness episodes and fewer numbers of days absent from day care/school/work in participants are the likely beneficial effects in individuals supplementing with a probiotic.

Studies on probiotics in athletes

Probiotic studies in athletes can be divided into one of two categories: general commentaries and reviews or randomised controlled experimental studies. A number of general commentaries and reports on probiotic supplementation in athletes have been published recently (Lamprecht & Frauwallner, 2012; Gleeson, 2013; Pyne et al., 2013). A summary of experimental studies detailing the subjects, probiotic species, dosage and clinical and immunological outcomes from 2006 is shown in Table II. We identified a total of 15 relevant experimental studies from an initial Medline search using the key term "probiotic athlete" but excluding commentaries, animal studies and review articles. The most commonly studied species in athletes and active individuals are *Lactobacillus casei*, *L. fermentum*, *L. acidophilus* and *L. rhamnosus*. The general approach in this type of study has been to determine the effects of probiotics on clinical measures of illness and immune function in a placebo-controlled experimental design. Some short-term studies (typically 4 weeks in duration) examining the physiological effects of probiotic supplementation (changes in gut microflora and immune function) are probably too short to realistically evaluate longer term clinical implications (West, Pyne, Peake, & Cripps, 2009). Experimental studies of probiotic supplementation in athletes should therefore investigate parallel changes in both clinical outcomes and immune function over a period of several weeks to a few months (Aagaard et al., 2013).

An initial study of probiotic supplementation in fatigued athletes presenting at a medical clinic was reported in 2006 (Clancy et al., 2006). At baseline, the whole-blood culture level of interferon-γ in the fatigued athletes was approximately half that of healthy control athletes. Subjects were supplemented with *L. acidophilus* at a dosage of 2.0×10^{10} cells per day for four weeks which restored interferon-γ secretion. These findings suggestive of a T-cell defect in fatigued athletes, and its reversal following probiotic therapy, are noteworthy given the central role that T-cells (and Treg cells in particular) play in immune homeostasis (Geuking et al., 2013). A number of research groups continue to explore the role of Tregs in maintaining inflammatory control in various athlete cohorts.

A double-blind, placebo-controlled cross-over trial investigated the use of *L. fermentum* in 20 elite male runners over a four-month winter training season (Cox, Pyne, Saunders, & Fricker, 2010). Athletes who were administered the probiotic for one month reported less than half the number of days of respiratory symptoms than the placebo group. Illness severity was also lower for episodes occurring during the supplementation period. To address the question of differences in response to probiotics between males and females, a randomised controlled trial involving a large number (n = 99) of physically active male and female adults was conducted (West et al., 2011). A substantial reduction in respiratory and gastrointestinal symptoms for males, but not females, was observed after 77 days of *L. fermentum* supplementation. Faecal microbial composition revealed that *Lactobacillus* numbers increased 7.7-fold (90% confidence limits 2.1- to 28-fold) in males receiving probiotic, while there was an unclear 2.2-fold (0.2- to 18-fold) increase in females receiving the probiotic. The number and duration of mild gastrointestinal symptoms were ~2-fold greater in the probiotic group. There was no apparent explanation for the differential clinical responses between males and females. The extent to which observed differences between the sexes are biological and/or environmental in nature is unclear.

At least three studies have examined the effects of *L. rhamnosus* supplementation. A randomised double-blind intervention study examined 141 runners taking either a placebo or *L. rhamnosus* for three months leading into a marathon (Kekkonen et al., 2007). There were no significant differences in the number of episodes of respiratory or gastrointestinal tract illness in the two weeks after the marathon. There was, however, a trend towards shorter duration of gastrointestinal symptom episodes in the probiotic group (4.3 d vs. 2.9 d in the controls). A more recent investigation examined the effectiveness of *L. rhamnosus* in combination with *L. paracasei* at a dosage of 2×10^9 cells per day for four weeks (Martarelli et al., 2011). Similar to a number of other probiotic studies, changes in immune function but not clinical measures were reported. The study was partially limited in the sense that it was not placebo controlled as the control group did not consume any supplements. In this study, supplementation with the

Table II. Chronology of studies from 2006 to 2014 involving the clinical and immunological effects of probiotic supplementation in trained individuals

Study References	Subject group/ Design	Supplementation	Clinical measures and outcomes	Immunological measures and outcomes
Clancy et al. (2006)	Active individuals (n = 18)/fatigued athletes (n = 9) Prospective single group intervention	*L. acidophilus*, 2.0 × 10^{10} cells per day in capsules for 4 wk	Not reported	Increased whole-blood culture secretion of interferon-γ post-supplementation. No effect on whole blood culture secretion of IL-4, IL-12 or salivary IgA concentration
Moreira, Kekkonen, Korpela, Delgado, and Haahtela (2007)	Marathon runners (n = 141) Placebo-controlled pre–post controlled trial	*L. rhamnosus* (LGG), milk-based drink 4.0 × 10^{10} CFU for 12 wk	No substantial difference in symptoms of atopy or asthma	The marathon induced a significant eosinopenia (~60%) but had no effect on serum eosinophil cationic protein or total IgE. No differences in changes were seen between groups receiving LGG or placebo
Kekkonen et al. (2007)	Marathon runners (n = 141) Placebo-controlled pre–post controlled trial	*L. rhamnosus* (LGG), milk-based drink 4.0 × 10^{10} CFU for 12 wk	↓duration of GI symptoms (2.9 vs 4.3 days) Trivial difference in mean number of healthy days (79 vs 73 days)	Haematological parameters within reference range for both groups throughout study
Tiollier et al. (2007)	French commandos 3-week training followed by a 5-day combat course. Placebo controlled	*L. casei*, milk-based drink for 4 wk	Trivial effect on URTI but a significantly greater proportion of rhinopharyngitis in the probiotic group (p < 0.05)	↑dehydroepiandrostane sulfate with supplementation. Maintenance of IgA concentration post-supplementation in probiotic but not placebo group.
Cox et al. (2010)	Distance runners (n = 20) Placebo-controlled pre–post controlled trial	*L. fermentum*, 1.2 x10^{10} as a freeze-dried powder in gelatin capsules.	↓50% lower number of days with illness with self-reported symptoms of respiratory illness	Twofold greater change in whole-blood culture interferon-γ with probiotic supplementation. No substantial differences in the mean change in salivary IgA and IgA1 levels, or in IL-4 and IL-12 levels
Martarelli et al. (2011)	Active individuals (n = 24) Pre–post controlled trial with control (but no placebo treatment) group	*L. rhamnosus, L. Paracasei* × 10^9 bacteria for 4 wk	Not reported	Both probiotics increased plasma antioxidant levels by ~9% (p<0.05), thus neutralising reactive oxygen species.
Gleeson et al. (2011)	Active individuals (n = 84) Placebo-controlled pre–post controlled trial	*L. casei* (Shirota) 1.3 × 10^{11} cells per day for 16 wk	↓36% proportion of subjects with URTI ↓ number of URTI episodes (1.2) compared with (2.1) over study period	Saliva IgA concentration was higher on *L. casei* than placebo (p = 0.03); this difference was not evident at baseline but was significant after 8 and 16 wk of supplementation. No significant effect on IgG, IgM and total immunoglobulin
West et al. (2011)	Active individuals (n = 80) Placebo-controlled pre–post controlled trial	*L. fermentum*, 1.0 × 10^9 cells per day in capsules for 11 wk	↓31% in illness load (duration × severity) of URTI in males but not females ↓ severity of GI symptoms in males	No substantial difference in lactoferrin, lysozyme and IgA. ~20–75% smaller perturbations in acute post-exercise anti-inflammatory and pro-inflammatory cytokines after probiotic supplementation
West et al. (2012)	Active individuals (n = 22) Placebo-controlled pre–postcontrolled trial	*L. paracasei, Bifidobacterium animalis, L.acidophilus, L. rhamnosus* at dose between 4.6 and 6 × 10^8 two prebiotics (raftiline and raftilose), lactoferrin (50 mg) and immunoglobulins (200 mg)	Not reported	Ninefold increase after probiotic supplementation in *L. paracasei* numbers and 50% smaller increase in serum IL-16. No substantial effects of either supplement on faecal short-chain fatty acid concentrations, measures of mucosal immunity or GI permeability

Table II (*Continued*)

Study References	Subject group/ Design	Supplementation	Clinical measures and outcomes	Immunological measures and outcomes
Välimäki et al. (2012)	Marathon runners (n = 127) Placebo-controlled pre–post controlled trial	*L. rhamnosus* GG 3 × 10^{10} cells per day for 3 months prior to marathon	Not reported	Probiotics did not have any substantial effect on serum LDL or antioxidants
Lamprecht et al. (2012)	Trained men (n = 23) Placebo-controlled pre–post controlled trial consisting of triple-step test cycle ergometry	Multi-species probiotics (10^{10} CFU/day) for 14 weeks	Not reported	↓zonulin in faeces (~25%), a marker indicating improved intestinal barrier integrity. Probiotic supplementation reduced TNF-α concentration by ~25% at rest and post-exercise, and exercise-induced protein oxidation by ~8%.
Gleeson et al. (2012)	Active individuals (n = 66) in endurance training Placebo-controlled pre–post controlled trial	*L salivarius*, 2 × 10^{10} CFU per day for 16 weeks	No substantial difference in frequency, duration or severity of URTI	No substantial difference in blood leukocyte, neutrophil, monocyte and lymphocyte counts; saliva IgA and lysozyme concentrations between *L. salivarius* and placebo
West et al. (2014)	Active individuals (n = 465; 241 males, 124 females aged 18–65yr) Placebo-controlled pre–post controlled trial	*B. lactis* Bl-04 2.0 × 10^{10} CFU per day; *L. acidophilus* NCFM and *B. lactis* Bi-07 5 × 10^9 CFU each per day as a powdered drink for 150 days	↓URTI frequency in the Bl-04 group (hazard ratio 0.73; 95% confidence interval 0.55–0.95; compared to placebo	Not reported
Haywood et al. (2014)	Rugby union players (n = 30) Single group cross-over design with 28-day washout period. Placebo controlled	*L. gasseri: 2.6 ×10^12, B. bifidum: 0.2 ×10^12, B. longum: 0.2 ×10^12 CFU in capsule form for 28 days*	Only 16/30 on probiotic experienced URTI or GITI whereas 24/30 did on placebo. ↓number of days with URTI in probiotic group (3.4) compared with placebo (5.8)	Not reported
Shing et al. (2014)	Runners (n = 10) Single group cross-over design with 28-day washout period. Placebo controlled.	45 billion CFU of *Lactobacillus*, *Bifidobacterium* and *Streptococcus* strains	↑increased run time to fatigue (min:s 37:44 ± 2:42 versus 33:00 ± 2:27; P = 0.03))	No significant effect of probiotic supplementation on lipopolysaccharide concentration. Small to moderate reduction in urine lactulose:rhamnose and a small reduction in gastrointestinal discomfort with probiotics. No significant effect on IL-6, IL-10 and IL-1ra.

URTI = upper respiratory tract illness; GI = gastrointestinal; GITI = gastrointestinal tract illness; CFU = colony forming units; IL = interleukin; IgA = immunoglobulin A; and IgE = immunoglobulin E.

dual formulation of probiotics increased plasma antioxidant levels.

Two studies have examined the effects of *L. casei* supplementation in healthy highly active individuals. Probiotic supplementation with *L. casei* by 47 French commando cadets during a three-week training course, followed by a five-day combat course, had little effect on the incidence of respiratory tract illness (Tiollier et al., 2007). Another study of active individuals involved 84 subjects consuming *L. casei* (Shirota) or placebo for 16 weeks. Subjects in the experimental (*L. casei*) group had substantially fewer upper respiratory illnesses with 36% fewer subjects reporting illness compared with the control group (Gleeson, Bishop, Oliveira, & Tauler, 2011). Better maintenance of salivary IgA levels was proposed as one possible explanation for the improved clinical picture in the probiotic group in comparison with the placebo group that exhibited a reduction in salivary IgA.

In 2012, there were a number of studies that examined probiotic supplementation ranging from 4 to 16 weeks in duration in various settings. Two of the studies employed a single probiotic (Gleeson et al., 2012; Välimäki et al., 2012), while the other two examined a multi-strain formulation (Lamprecht et al., 2012; West et al., 2012). Notably, only one of the four studies reported clinical measures of upper respiratory illness (with no clinically significant effects) and the immunological measures were different in each case (salivary IgA, white blood cells and antimicrobial protein concentration; serum low-density lipoproteins and antioxidants; gut permeability markers; and serum cytokines) in a variety of pathology specimens including blood, saliva and faecal samples. This diversity of biomarkers illustrates the challenge in clearly identifying the immunological, physiological and health benefits of probiotics in various groups of athletes.

From a practical perspective, the magnitude of translational outcomes or clinical benefits is the key consideration for athletes and coaches. A large clinical trial (n = 465 active adults) investigating the effects of *B. lactis* for 28 days reported a 27% reduction in the frequency of URTI, although the 95% confidence interval around the estimate implies that the true underlying reduction was most likely between 5 and 45% (West et al., 2014). A smaller sports-based study on rugby players (four weeks of a multi-species probiotic supplement) also reported a 27% reduction in the frequency of URTI (Haywood et al., 2014). The mean duration of URTI was two days less in the probiotic group. Of particular interest is a small cross-over study of 10 runners taking a multi-species formulation of *Lactobacillus*, *Bifidobacterium* and *Streptococcus* strains (Shing et al., 2014). A moderate enhancement of run time to fatigue in hot conditions with probiotic supplementation was observed, accompanied by reductions in gut permeability and gastrointestinal discomfort in comparison with the control group. Future studies of probiotics need to include measures of athletic performance to accompany clinical measures of illness and underlying immune and inflammatory markers.

Taken together these studies in athletes provide modest evidence that probiotics can provide some clinical benefits in athletes and other highly active individuals. The difficulty in interpreting the studies is illustrated by variations in clinical outcome measures. Of the 15 studies in this analysis, a total of six did not report any clinical data on illness or symptoms of illness. Furthermore, a failure to report against defined primary outcomes makes it difficult to interpret the true effects of supplementation. Only one study reported directly an ergogenic effect of probiotics on sporting performance (Shing et al., 2014). However, 10 out of 13 studies reported beneficial changes in immune and inflammatory markers. Similarly, a recent review of probiotics in respiratory virus infections in the general population showed that 28 out of 33 studies reported beneficial effects (King et al., 2014). Given the small number of studies, and substantial variation in experimental approaches, dependent measures and outcomes, more well-designed studies of probiotic supplementation in various athlete groups are warranted. These studies will clarify the issue of clinical/practical significance of reported benefits in addition to statements of statistical significance (Stapleton, Scott, & Atkinson, 2009).

Practical recommendations for athletes

Several practical strategies have been suggested for more effective usage of probiotic supplementation in the sporting community (Figure 1). Although probiotics are most well known in relation to their purported effects in moderating common gastrointestinal illnesses, the purported benefits in the respiratory tract (West et al., 2011) could be useful for athletes experiencing recurrent or persistent common cold and flu-like symptoms. Athletes contemplating

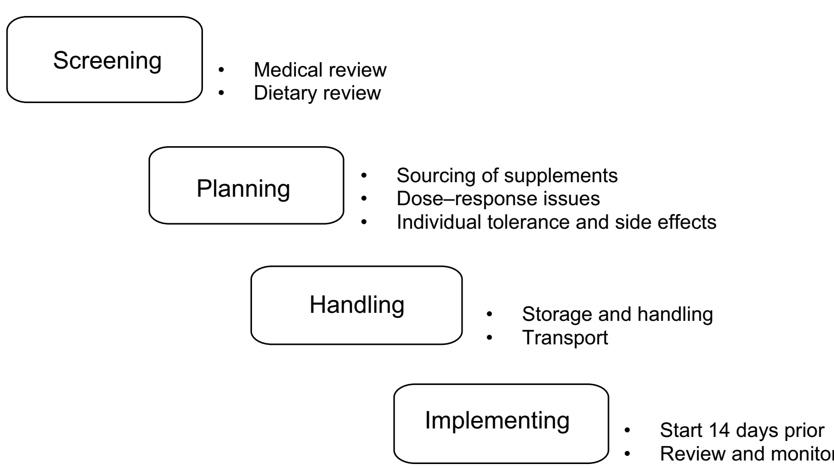

Figure 1. Practical issues for athletes considering the use of probiotic supplementation.

the use of probiotic supplementation should do so on the basis of informed choices and practitioner involvement. Physicians and dieticians should review health care and consumer information on specific applications, dosage and possible contraindications of probiotic supplementation for each individual athlete. Supplementation should be considered as part of a full dietary review given that nutrient needs should be met by consumption of wholefoods rather than supplements – recommendation of dietary supplements to developing athletes might overemphasise their importance in comparison to other training and dietary strategies (Desbrow et al., 2014). In this context, it is also important to remember that some probiotic products contain energy and carbohydrate that can form part of an athlete's overall nutrition plan. Only reputable sources of commercially available supplements should be used to reduce the risk of contaminants that might contravene doping in sport regulations (Maughan, 2005). Athletes should be educated on the likely risks of contamination given that the World Anti-Doping Agency enforces a principle of strict liability for positive test results involving banned substances. Different formulations of probiotics from tablets or capsules to powder (added to drinks) or probiotic-enriched chews (Lehtoranta et al., 2014) are available to meet individual preferences.

Although probiotic supplementation and their possible health benefits have generated substantial interest in the general and sporting communities, it can be difficult to obtain or source particular strains or formulations recommended by a physician or dietician. Sufficient time must be allowed for sourcing of specific probiotic formulations particularly if they are not available in local settings. Probiotic supplementation should be trialled during the preseason phase, or otherwise the early- to mid-stages of a competitive season, so the athlete is familiar with taking the supplements. Dose–response studies are best conducted under controlled conditions of a research trial, but case or case-control study analysis of group and individual athlete responses should be useful. A short-term trial of probiotics is useful in characterising individual tolerance and the presence of any adverse effects.

Probiotic supplements should be packaged, stored, handled and transported in an appropriate manner. The original proprietary containers (with instructions) should be retained and used where possible to avoid traversing international borders with unidentifiable nutritional supplements. Athletes should take particular care in warm to hot environments and avoid, where possible, leaving supplements outdoors for long periods in direct sunlight, in a motor vehicle or near an oven or other heat-generating appliances. New technology has led to probiotic supplements that do not require refrigeration, which may be ideal for athletes during travel. Supplements should also be kept dry at all times. During travel it might be useful for individuals to keep probiotics with other nutritional supplies, supplements, ergogenic acids or medications, or held by team personnel as required.

In terms of implementation, probiotic supplementation should commence at least 14 days before overseas travel or a major training camp or competition to allow adequate time for colonisation of bacterial species in the gut. A particular issue is the increased risk of gastrointestinal problems during international travel, particularly to countries with challenges related to food hygiene and associated risk of gut illness (Shaw, Leggat, & Chatterjee, 2010). Prophylactic supplementation with probiotics for individuals and athletes travelling to these regions or areas could form part of an overall illness prevention plan. Tolerance and side effects should be monitored by the athlete, coach and support staff and a medical opinion sought if there is ongoing concern. It is not unusual to experience transient increased activity in the gut during the colonisation period (e.g stomach rumbles, increased flatulence) and athletes should be informed that mild side effects for a few days are not uncommon (West et al., 2011). Athletes should be encouraged to review and monitor probiotic consumption on a daily basis to promote compliance and best practice usage. Compliance might be improved by having athletes take the probiotic supplement at the same time each day – for example at breakfast time.

Conclusions

It appears that probiotic supplementation can yield small beneficial effects in promoting health in trained individuals. Probiotics may reduce the risk of respiratory and gastrointestinal illness during stressful periods of training and competition. The clinical benefits of probiotics are most likely mediated by changes in gut microbiota and enhanced mucosal barrier integrity in the gastrointestinal and respiratory tracts. Practical issues around probiotic supplementation include medical and dietary review of individual athletes, exposure to probiotics well before competition to establish individual tolerance and possible side effects and daily monitoring during periods of intensive training and competition. More research is required to clarify issues of strains, dose–response, mechanisms and best practice models for probiotic implementation in the sporting community.

Funding

The authors have been the recipients of research funding from Probiomics Ltd, Probiotec Pharma Pty Ltd, Christian Hansen A/S and DuPont Nutrition and Health.

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