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Author

Leite, Geovana SF, Resende, Ayane S, West, Nicholas P, Lancha, Antonio H

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Highlights

Specific strains of probiotics appear to be effective in minimizing GI and URS

The effects are dependent on the species, dose, period and form of administration

Probiotics effect related to URS are local and involves the increase of IFN-ϒ and IgA

The effects related to gut comprising mainly the increase of barrier function

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Nutrition & Exercise: thinking out of the box.

Probiotics and sports: is it a new magic bullet?

Geovana SF Leite[1], Ayane S Resende[1], Nicholas P West[2], Antonio H Lancha Jr[1]

1 - Laboratory of Nutrition and Metabolism Applied to Motor Activity, School of Physical Education and Sports, University of Sao Paulo, Sao Paulo, Brazil

2 - Menzies Health Institute Queensland and School of Medical Science, Griffith University, Griffith Health Gold Coast Campus, Southport, QLD 4222, Australia

***Corresponding author:** Geovana S.F. Leite. School of Physical Education and Sports, University of Sao Paulo, Brazil. Avenue Professor Mello Moraes, 65 - Cidade Universitária - 05508-030 - São Paulo – SP. +55(11)30913096.

Keywords: Probiotics, athletes, sports, exercise, immune response, gastrointestinal tract,

List of abbreviations

URS: respiratory illness symptoms

GI: gastrointestinal

LPS: lipopolysaccharides

SCFA: short chain fatty acids

NK: Natural Killer

IgA: Immunoglobulin A

IFN-γ: Interferon-gamma

CFU: Colony forming Unit

VO_{2max}: Maximum oxygen consumption
HMB: β-Hydroxy-β-Methylbutirate
GALT: Gut Associated Lymphoid Tissue
TLR-2: Toll like receptor-2
NF-κB: Nuclear factor kappa B
MyD88: Myeloid differentiation primary response 88
HPA: hypothalamic-pituitary-adrenal

Introduction

In sports field is discussed that athletes may be at risk of several disorders due to an exhaustive training load, exercise intensity, travel, inadequate rest and poor nutrition[1,2]. Strenuous exercise promotes immunodepression, oxidative stress, increased respiratory illness symptoms (URS) and gastrointestinal (GI) disorders[3,4]. Moreover, especially athletes of long distance sports (marathon, triathlon and ultra-endurance), commonly report health issues and endotoxemia[1,5,6]. Thus, there is a growing scientific body looking for strategies, especially in the nutritional supplementation field, to prevent these conditions from impacting sporting performance[4].

In this context, probiotic supplementation has gained special attention due to evidence of a beneficial effect on respiratory and gastrointestinal tract symptoms[1,7,8]. The beneficial effects of probiotics may indirectly influence the performance of athletes by preventing illness negatively affecting performance[9]. Probiotics are considered a safe strategy to use in athletes; however it is difficult to reproduce study outcomes with athletes around the world. Perhaps, the different results found may be from different interventions, such as use of different probiotics strains or multi-strains, time and dose of consumption, along with the use of different athletic cohorts[8,10,11]. Currently, there is no consensus about whether probiotics may have an ergogenic effect or improve recovery beyond improving resistance to infectious and non-infectious agents that underpin illness conditions. In this sense, the goal of this present review is to examine the main mechanisms by which probiotics can contribute to sporting performance and the major differences among the interventions which interfere in the outcomes. Our focus is on the main benefits and practical issues of probiotics consumption concerning immune response, gut disorders and athletes' performance.

Probiotics consumption in the sports environment: evidence for efficacy

Immune health in athletes

Heavy training periods and/or a heavy schedule of competitions increase the risk of illness, in particular upper respiratory tract illness (URS) symptoms in athletes. URS include coughing, congestion, sneezing, sore throat and mucous production. The risk of illness is considered acutely greater in the immediate post-exercise period; a phenomenon termed the "open window" hypothesis. Evidence strongly indicates that in this window there is decreased host protection with reduced NK cells number and activity, low neutrophils activity, impaired proliferation of T-lymphocytes and decreased levels of salivary IgA[8,12,13], which contributes to virus and bacteria get able to establish infection and causing illness.

Exercise immunology studies reported that declines in salivary IgA precede URS episodes and symptoms in athletes[13,14]. Recurrent URS symptoms, particularly in heavy training may impact athlete performance depending on the severity of illness symptoms and the requirement to alter training. The most likely causes of compromised immune activity are increased serum levels of contra-regulating hormones cortisol and catecholamine produced during vigorous exercise[13]. Several points are linked with this phenomenon such as poor nutrition strategies during and after the training session, lower micronutrients and macronutrient intake, insufficient recovery time, and an exhaustive high-level competition schedule. Together, these issues contribute to increasing contra-regulating hormones and consequently driving immune perturbations[4,15].

Probiotic supplementation and athlete health

A body of evidence supports that some probiotic supplements may attenuate the risk of URS and/or reduces the duration and severity of symptoms in athletes. Some studies also indicate that probiotics may alter serum cytokine concentrations and maintain salivary IgA concentrations (table 1). A pivotal study by Clancy et al. (2006) provided early evidence for a role for probiotics in modifying the immune system[16]. This study investigated the relationship between *L. acidophilus* ($2x10^{10}$ per 4 weeks) in recreational athletes with fatigue whom exhibited a decrease in IFN-γ production by CD4 blood cells (compared to non-fatigue athletes). The authors found that after *L. acidophilus* consumption, both healthy and fatigued athletes exhibit an increase in IFN-γ production by T-cells, and non-fatigue athletes exhibit an increase in salivary IFN-γ concentration. The findings of this study suggest that baseline immune status may dictate responses to probiotic supplementation.

A number of studies have examined the effect of probiotics on URS. Cox et al. (2010) conducted a study with a specific probiotic strain (*L. fermentum)* in high trained runners[17]. This consumption was capable to reduce the number of day symptoms of URS with a trend toward a lower a severity of illness. West et al. (2011) [18] in study with the same probiotic strain utilized by Cox[17] with minor dosage and longer period application found that after the intervention male shown a decrease of URS symptoms and females presents an increase of this symptoms. Moreover, this article present dates related to cytokine response after the exercise that was modified by probiotic use[18]. The cytokines raise less after acute exercise at the intervention group. It maybe done by a better immune regulation associated to *L. fermentum* supplemented. Nonetheless, Kekkonen et al. (2007) found a modest increase in IgA and IFN-γ in probiotic group but no statistical significance was found with use of *L. rhamnosus* GG ($40x10^9$CFU/day)[19].

Gleeson et al. (2011) in a work with well-trained endurance athletes consuming fermented milk containing the commercial available probiotic *L. casei* Shirota during a longer period of utilization (4 months) demonstrated that the URS and episodes were lower in probiotic group[7] (Table I). Also, salivary IgA production was higher in probiotic group after 8 and 16 weeks of intervention. This study highlights benefit from probiotics in endurance athletes would be useful.

West et al. (2014) research with physically active participants rather than athletes compared a monostrain and double strains probiotics[20] (Table I). The results demonstrated that the monostrain *B. lactis* resulted in a 27% reduction in URS compared to placebo while the double strain probiotic resulted in a 19% non-significant decrease of URS risk. This study showed for the first time that healthy active people, generally considered at the lowest risk of URS, could benefit from a probiotic supplement.

Haywood et al. (2014) conducted an interesting study with probiotic in Rugby players with a higher dose multi-species probiotic (4 weeks)[11]. All the subjects in placebo group reported URS higher than probiotic group, the duration and severity of the URS episodes and symptoms was not different between groups, but the number of illness days in placebo groups was a trend to be higher when compared to treatment[11].

Strasser et al. (2016)[15] with a similar multi-strain probiotic utilized by Lambrech[21] presented that this commercial multi-species is capable to reduce URS. Subjects that showed more symptoms had higher degradation of tryptophan and kynurenine/tryptophan ratios during the exercise. After probiotic intervention the probiotic group had a smaller decrease in tryptophan concentration after exercise compared to placebo. These data confirm the efficacy of the probiotic in attenuating the URS.

According to Michalickova et al. (2016)[22] study with a long period utilization of capsules containing *L.s helveticus* Lafti® L10 in high concentration ($2x10^{10}$ CFU/day), this probiotic is effective to reduce the length of episode and the number of URS. Similar result was seen by Cox et al. (2010)[17] and West et al. (2011)[18] with use of *L. fermentum* VRI-003 (PCC) and Gleeson et al. (2011)[7] with fermented milk containing *L. casei* Shirota. Moreover an increase in CD4/CD8 ratio was found in probiotic group. These authors suggested that low CD4/CD8 ratio is normally related to acute viral diseases and an improvement in this immunological parameter could contribute to the favorable effects of Lafti® L10 on URS.

Specific probiotics strains attenuate URS[17,18,22], however the data with non-athlete subjects is quite small. And no alterations in cellular activity were found to explain the reduction of the URS found in the probiotic group[22]. Perhaps looking for immune cells function may contribute to clarify the decrease of illness symptoms/severity. Also, the local modulation and interaction warrant attention such as the use of saliva (eg: IgA, lisozime, α-amilase) and feces (Zonilun; SCFA; α-1-anti-tripsin; ocludin; IgA) measures as analytical material. Besides that majority of studies monitored the dietary supplementation utilized by athletes but there is no sufficient information about participant consumption. These are valid information that can contribute for future works in order to discuss and justify the results.

Gut health and permeability

GI disorders are often reported in different situations in athlete routine, mainly in endurance sports. For instance, Pugh et al. (2018) have observed from 249 athletes of several sports one symptom at least (86% reported), varying between mild and moderately severe, and that upper abdominal discomfort, flatulence and urgent need to defecate were most common[6].

As opposed to moderate regular exercise, physical and psychological stress produced by both a high training load and exercise intensity cause disruption in the intestinal epithelium and barrier function. Hyperthermia and redistribution of blood flow cause ischemia and hypoperfusion in the intestinal environment, besides of the overstimulation of hypothalamic-pituitary-adrenal (HPA) axis are examples of exercise-induced stimuli[3]. This gut barrier is crucial for preventing the translocation of pathogenic bacteria and endotoxins, such as LPS. The increase in gut permeability favors the translocation of LPS and bacteria into the intestinal system and bloodstream which can result in endotoxemia[23]. For instance, endurance athletes often present elevated plasma LPS concentrations and the majority may have endotoxemia[5,23].

Currently, there are few studies that have evaluated the effect of probiotics regarding gut permeability and endotoxemia (Table I). However these studies have demonstrated positive outcomes with a significant reduction of fecal zonulin concentrations[21] and plasma endotoxin concentrations[24,25]. Interestingly, these studies have used a multi-strain probiotics supplement containing in common the species *L. acidophilus*, *B. bifidum* and *B. animalis* subsp. *lactis* for at least 1 month[21,24,25]. It is also believed that chronic interventions with longer periods of probiotic consumption are better for intestinal benefits, since Gill et al. (2016) with 1 week of *L. casei* consumption did not observe effect on endotoxemia[10].

Moreover, the majority of studies performed with this population have shown better results for improvement of GI symptoms, mainly regarding to their severity, episodes and duration (Table I). Some studies did not show statistical differences between probiotic and placebo group West et al. (2011)[18]. Still, clinically, athletes have reported an improvement especially with regard the severity of these symptoms in training periods[11,19,25]. *Lactobacillus* and *Bifidobacterium* species, especially *L. acidophilus, L. rhamnosus* GG and *B. bifidum* seems to be interesting to improve exercise-induced GI symptoms.

Probiotics also interact with the resident gut microbiota and may affect their composition. West et al. (2011) have observed an increase of *Lactobacillus* genus by 7 times after 11 weeks of supplementation of *L. fermentum* which may suggest an effect of probiotics in gut microbiota composition[18]. Martarelli et al. (2011) have also supplemented athletes with *Lactobacillus* species and, at the end of the study, observed a significant augment of *Lactobacillus* count in feces[26]. Lactic acid bacteria produce lactate that is converted by butyrate-producing bacteria into butyric acid. This SCFA is pivotal for intestinal homeostasis because of its several benefits in the intestinal cells, mainly, barrier function and permeability since the butyrate upregulate thigh junction proteins[27]. In addition, it seems that symbiotic supplementation may have an additional effect on GI symptoms and gut permeability as reported by Roberts[25]. On the other hand, West et al. (2012) in a study with non-athletes did not observe differences between symbiotic and prebiotic groups regarding to SCFA production, neither on gut permeability[28]. Still, the effect of probiotics, prebiotics or symbiotic on SCFA production and gut permeability in athletes is still not elucidated.

Table -1 – Studies related to Probiotic use in sports

Reference	Subjects	Probiotics	URS Outcomes		GI Outcomes		Further considerations
			Subjective	Biological	Subjective	Biological	
Active Individuals							
20	Health active subjects(n=465)	Sachets containing $2x10^9$ *B. lactis* subsp lactis Bl-04) or Double strain (*L. acidophilus* NCFM $5x10^9$ and B. *animalis* subsp. lactis Bi-07 $5x10^9$ UFC/day during 5 mouths	*B. Lactis* was effective to reduce the URS episodes compared to placebo and Bi-07	NR	24% reduction in risk of illness in both probiotics groups compared to placebo	NR	RDBPCT Placebo group and Bi-07 group showed different level of physical activities (intensity and duration). 8 individuals present some type of GI illness with majority in the probiotics groups(7 vs 1 placebo).
Athletes							
16	Recreational athletes healthy athletes(n=18); fatigued athletes(n=9) (male/female)	Capsules containing $20x10^9$ CFU/day L. *acidophilus* LAFTI L10 during 4 wk	Fatigued athletes present more episodes of Upper respiratory illness/year and lost more activities related to it	Before probiotic use, fatigued athletes showed a decrease of IFN-γ production by CD4 compared to non- fatigued athletes .After probiotic use, fatigued athletes exhibit an increase in the IFN-γ production by CD4 cells, and non- fatigued athletes exhibit an increase in salivary IFN-γ	NR	NR	Both groups received the intervention Fatigued athletes(20.9h) had higher training volume compared to non-fatigued(10.7h)

Table I (continued)

19	Marathon runners (*n*=119)	Milk-based fruit drink containing *L. rhamnosus* GG ($40x10^9$CFU/day) during 3 months	*L. rhamnosus* GG had no effects related to URS Incidence compared to placebo	NR	Duration of the GI-symptoms was 33% shorter during the training period and 57% shorter 2wk after the marathon in the probiotic group	NR	RDBCP Probiotic consumption varied the quantities ($1x10^{10}$ and $4x10^{10}$/per day) and type of administration. No significant difference in GI-illness episodes between groups Study was conducted during a summer training period
17	Elite male runners athletes (n=20)	Capsules containing *L. Fermentum* VRI-003 (PCC) $12x10^9$CFU/day during 4wk	Probiotic group present a reduction in number of days with illness symptoms	Probiotics group present a modest increase in IgA and IgA1 salivary concentration but no statistical significance was found A modest increase in IFN-γ production was found in probiotic group without statistical significance	NR	NR	RDBCPC The runners that participated of the study competing in events from 800 m to the marathons(42.2 km) The study was conducted during a winter training period
18	Competitive cyclists (male=64/female=35)	Capsules containing L. *fermentum* VRI-003 (PCC) $1x10^9$CFU/day during 11wk	For males the probiotics were effective by decreasing URS	The cytokines relies after the acute exercise were attenuated in probiotic group	Lower severity score of GI symptoms in males of the probiotic group at high training loads	Increase of 330% of *Lactobacillus* genus numbers in the probiotic group with a 7.7-fold difference between groups	RDBCP Study was conducted during the winter training period Intervention results were different between males and females Probiotic group reported 2x more mild GI illness episodes (number and duration) than placebo group.

Table I (continued)

7	Endurance Athletes(n=58) (male/female)	Fermented milk containing *L. casei* Shirota $6.5x10^9$CFU/2 times per day during 16 wk	Placebo group had significant more URS and episodes compared to probiotic group	Salivary IgA concentration was higher after 8and 16 wk of probiotics intervention Placebo group decrease the IgA concentration during the study	NR	NR	RDBCP Study was conducted during training period; The mean of training hour/wk was 10 hrs. The fermented milk was ingested together with breakfast(first) and in the evening(second)
36	Endurance Athletes(n=66) (male/female)	Sachets containing *L. salivarius*, $2x10^9$CFU/day during 16 wk	No difference between groups related to URS duration	No difference related to IgA salivary level Probiotic group showed an increase of lymphocytes total account after the intervention	NR	NR	RDBPC Similar to Gleeson [7]
21	Male Athletes (n=23)	$1x10^{10}$ CFU/day of a multi-species (*B. bifidum* W23 + *B. lactis* W51 + *E. faecium* W54 + *L. acidophilus* W22 + *L. brevis* W63 + *Lactoc. lactis* W58) in a sachet with a matrix* during 14wk	NR	NR	NR	Significant reduction of zonulin concentrations in probiotic group	RDBCP No differences in α-antitrypsin concentrations It was included . triathletes, runners and cyclists

Table I (continued)

11	Elite rugby players (n=30)	Capsules containing L. *gasseri* 2.6x10^9 B. *bifidum* 2.6x10^9 B.*longum* 2x10^{8}CFU/day during 4 wks	Probiotic group reported less URS during intervention	NR	Significantly lower presence of GI symptoms episodes after probiotic consumption	NR	Cross-over design. This study during a winter training period.
24	Male runners (n=10)	45x10^{9}CFU/day of a multi-species (*L. acidophilus* + *L. rhamnosus* + *L. casei* + *L. plantarum* + *L. fermentum* + *B. lactis* + *B. brevis* + *B. bifidum* + *S. thermophilus*) in capsules during 4wk	NR	NR	NR	Significant lower plasma LPS concentration after probiotic consumption compared to baseline Moderate reduction in GI permeability in probiotic group	Cross-over design.
10	Endurance male runners (n=8)	Beverage containing *L. casei* 1x10^{11}CFU/day during 1 wk	NR	No difference in cytokine profile in probiotic group after intervention	NR	No effect on endotoxemia	RDBCP Probiotic group showed a trend do increase the inflammatory parameters after intervention

Table I (continued)

14	Recreational athletes (male=155/ females=113)	Fermented milk containing *L. casei* Shirota $6.5x10^9$CFU/2x per day during 5 months	No differences related to URS, number of episodes and duration of illness	The level of IgG specific antibodies for cytomegalovirus (CMV) and Epstein Bar Virus in probiotic group was lower after intervention when compared to baseline of the same group	NR	NR	RDBCP Fermented milk was ingested together with breakfast (first) and in the evening meal (second) Subjects ranged of sports such as triathlon, swimming, cycling, distance running, tennis, squash, badminton, football, rugby, hockey, lacrosse, basketball, Self-reported training load was 11 h/week.
22	Athletes (n=39)	Capsules containing *L. helveticus* Lafti® L10 $2x10^{10}$CFU/day during 14 wks.	The number of URS, duration and episodes illness was shorter in probiotic and increase of vigor after treatment.	Probiotic group present increase in CD4/CD8 T lymphocyte ratio after intervention	NR	NR	RDBPC Athletes modalities: badminton, triathlon, cycling, alpinism, athletics, karate, savate, kayak, judo, tennis and swimming Subjects were instructed to take capsules every day after the breakfast. Athletes had a mean of 11 h/wk training
25	Recreational triathletes (n=30) (males/females)	$2x10^{10}$CFU/day of *L. acidophilus* + $9.5x10^9$ CFU/day of *B. bifidum* $0.5x10^9$ *B. animalis* subsp. *lactis* + 55.8mg/day FOS in capsules during 12 wk	NR	NR	GI symptoms episodes were lower in the probiotic + FOS group at each month of training pre-race, and the severity of GI symptoms	Reduction in plasma endotoxin levels at pre-race and 6 days post-race (~26%), as well as for IgG levels observed 6 days post-race. Also, probiotics + FOS group had the lower increase in GI permeability when compared to other groups	RDBCP There was a group with probiotic + FOS + α-lipoic-acid and N-acetyl-carnitine hydrochloride, but it was observed better overall outcomes for the probiotic + FOS group(LAB[4])

15	Endurance Athletes (n=30)	Sachet with a matrix* Containing $1x10^{10}$CFU multi-species *B. bifidum* W23 + *B. lactis* W51 + *E. faecium* W54 + *L. acidophilus* W22 + *L. brevis* W63 + *Lactoc. lactis* W58) during 3 months	Probiotic group showed less URS after treatment	After the acute exercise, probiotic group decrease less tryptophan level	NR	NR	RDBCP Female subjects showed higher degradation of tryptophan compared to males Probiotic group present higher amount of training per week compared to placebo

Legend: B.: *Bifidobacterium*; E.: *Enterococcus;* L.: *Lactobacillus;* S.: *Streptococcus*; Lacto.: *Lactococcus;* URS: Upper respiratory illness symptoms; *: matrix consisted of cornstarch, maltodextrin, vegetable protein, $MgSO_4$, $MnSO_4$ and KCl; CFU: colony forming units; RDBCP: randomized, double-blind, controlled, parallel groups design; wk: weeks. NR: Not Reported

Recovery and strength exercise

Recently articles target the possible link between probiotics use in muscle repair[29]. Although these authors propose that probiotics may sped up muscle repair. These evidences refer to resistance training and in addition to other nutritional supplements that have direct influence on protein synthesis (eg: whey protein, HMB). Furthermore the main purpose of these studies were the possible increase in proteins absorptive capacity with probiotic[29,30] or recovery process, while immune cell parameters was not evaluated. Indirectly probiotics may lower muscle repair process time[29].

Furthermore, in strength sports, probiotics may contribute to muscle hypertrophy processes[29] or associated to the regulation of intestinal health. Strength athletes normally have a high consumption of proteins which can lead to an increase in the production of hydrogen sulphate. This later may be detrimental to intestinal health[39]. Preserve the athletes health indirectly aid sports performance. Hence it seems that probiotics may have clinical contributions through different ways in sports modalities.

Proposed mechanisms of probiotics action

The main ways that probiotics may act is to enhance the barrier function, stimulating immune cells activity (regulating the pro/anti-inflammatory pathway and immunoglobulins production), increasing SCFA production, lowering intestinal pH and stimulating mucus production [1,2].

In sports context, articles suggest possible mechanisms by which probiotics may improve immune function of the athletes related to increase of IFN-γ production by T lymphocytes[16,17] and possible link to increase of IgA production by B-lymphocytes[17]. According to Glück (2003), immune cells can traffic from one mucosal site to another in the body and the stimulation at one site (eg: intestine), can result in effects detectable at another site (eg: respiratory tract)[31].

Regarding to gut permeability, the authors suggest that TLR2 activation may culminate in tight junction protein production, especially zonulin, that occurs with the probiotic use[21]. As reported by Cario et al. (2007)[32] and Well et al. (2011)[33]; this occurs via toll like receptor-2 (TLR-2) present in the gut cell surface which activates the inflammatory cascade stimulating NF-κB transcriptor factor and MyD88, that in a tonic level activation, preserve the epithelial intestinal integrity (Figure 1). Commensal bacterial stimulation of TLR2 in the intestinal epithelium may be necessary for intestinal homeostasis and prevent endotoxemia[25].

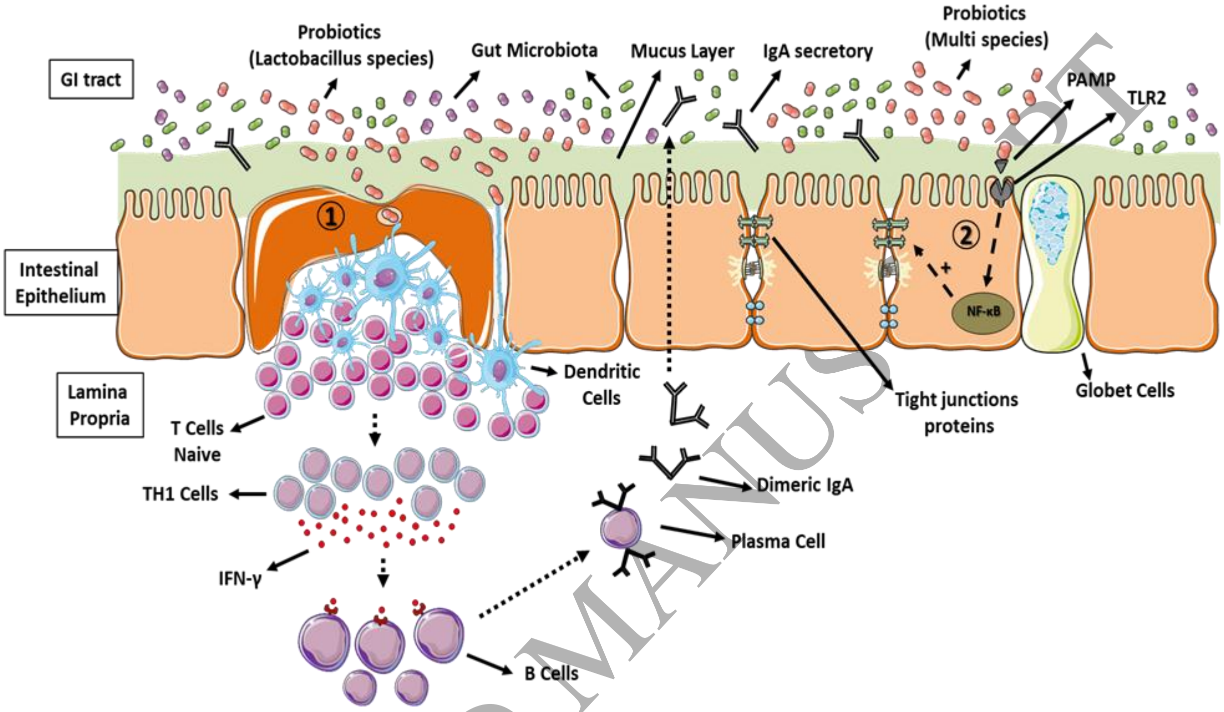

Figure 1. Probiotics effects on gut barrier. 1) *Lactobacillus* species may have a role on IgA secretory production via IFNγ-producing Th1 cells pathway[16,17]. These species influence the mucosal immune system by interacting with intestinal epithelial cells, M cells and dendritic cells. The GI mucosa interconnects with upper respiratory tracts which may explain the improvement in GI symptoms and severity of URS[7]. **2)** Specific probiotics stimulate TLR2 signaling through its molecular patterns (PAMPs) leading to an inflammatory response (NF-κB pathway). The inflammatory mediators may cause positive adaptations in the intestinal barrier in order to control this response. **Legend:** GI: gastrointestinal; TRL2: toll like receptor 2; PAMP: pathogen-associated molecular pattern; NF-κB: factor nuclear kappa B; IFN-γ: interferon gamma; TJP: tight junction proteins.

Which factors may influence probiotics outcomes?

It is seems that exist a minimum time for probiotic use to induce the positive effects expected in the immune system of athletes. In a study by Gill et al. (2016) with short term high dose probiotic utilization (L. *Casei* $1x10^{11}$ per 7^{th} days) the probiotic group did not demonstrate alterations in systemic cytokine profile or gut permeability compared to placebo[10]. Majority of studies that showed positive effects employed long periods of probiotics apply[7,14,15,18-22,25].

Some authors[11,17,24] have demonstrated probiotic consumption during 4 weeks with positive effects related to URS and GI symptoms. Both the Haywood and Shing studies employed a multi-species with increased load and dose per strain[11,24]. Perhaps this explains their results. Multi-species supplements with different characteristics have an enhanced colonization chance, and display synergistic effects with specific properties to enhance the chance of survival and adhesion. Moreover, the positive interrelationships between strains may increase their biological activity. Colonization of probiotics species is probably host-dependent, because of gastrointestinal complexity and variability[34].

Cox et al. (2010) have demonstrated a reduction in number of days with illness symptoms and a modest increase in IgA salivary concentration employed a mono-strain *(L. fermentum* VRI-003 (PCC); $12x10^{9}$CFU/day)[17]. As reported by authors, this specific probiotic strain has a potential to colonize the intestinal tract, and this may justify the described result.

Conclusion and future perspectives

Specific probiotics (or multi-species) appear to be effective in minimizing GI and URS and perhaps post-exercise recovery. These effects are dependent on the species, dose, period and form of administration (capsules, sachets, fermented milk). The cellular mechanisms related to the effectiveness of probiotics in the sports context have not yet been elucidated and less articles appoint biological assessments. These possible mechanisms of action of probiotics already described in studies outside of sports. It is suggested that future research consider parameters such as SCFA production, pH changes, barrier function-related proteins, microbiota composition and immunological cells function modulated by exercise intensity and duration.

Declarations of interest: None

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