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THE ATHLETE GUT MICROBIOTA: PRACTICAL NUTRITION STRATEGIES TO SUPPORT THE ATHLETE'S GUT AND IMMUNE HEALTH

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Athletes require precise and personalised nutrition strategies to achieve peak performance. Together with training, these nutrition strategies facilitate the physical, physiological and metabolic adaptations that underpin enhanced athletic ability. In recent years, researchers have begun to explore how training and nutrition can influence the athlete's microbiota and vice versa.

THE HUMAN GUT MICROBIOTA

The human gut microbiota is a community of microorganisms that populate the gastrointestinal tract (GIT). Every individual hosts a unique, rich, and diverse ecosystem that is comprised of trillions of bacteria, including at least 160 different species[1]. Our relationship with the gut microbiota is symbiotic; we provide an environment for the microorganisms to live and nutrients for them to feed on. In return, they participate in several functions that are important for human health, such as nutrient uptake, fermentation of non-digestible dietary fibres, vitamin synthesis and prevention of colonisation by pathogenic microorganisms[2].

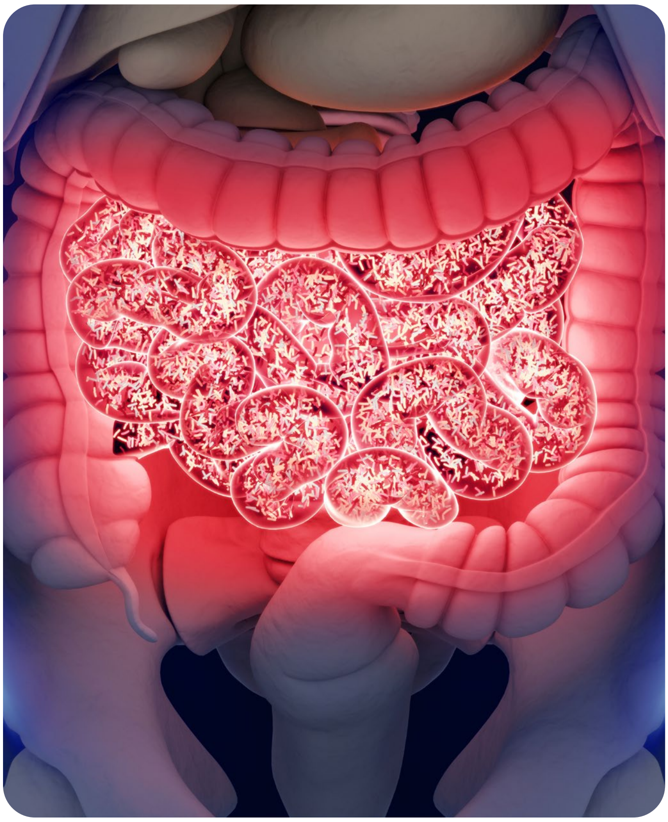
While there is no consensus as to what constitutes a 'healthy' microbiota, it is generally considered that the microbiota is optimal when it is diverse, resilient and stable[3]. Studies have shown that these characteristics are associated with healthy long-living people and the absence of certain gut-microbiota associated diseases. Many factors, including age, medication, stress and the environment, as well as diet and exercise, can affect the function and composition of the gut microbiota.

THE ATHLETE MICROBIOTA

Early research suggests that the gut microbiota of physically active individuals contains a greater abundance of beneficial bacterial species and greater bacterial diversity[4]. More specifically, lean body mass and VO_{2max} have been positively correlated with microbial diversity and metabolic function, and greater populations of bacteria which can modulate mucosal immunity, improve gut barrier function, and synthesise short-chain fatty acids (SCFAs). Other factors common amongst athletes, such as fibre intake, diversity of dietary plant intake, time spent outdoors, and possibly other genetic factors are likely to also contribute to this beneficial microbial community[4].

A single bout of exercise may also transiently modify the intestinal microbiota[4]. Certain metabolites produced during exercise, such as lactate, can be resorbed by the gut and selectively used as an energy source by certain bacterial species[5]. Excessive exercise, however, may have a deleterious effect on the gut. Prolonged, strenuous exercise can perturb gastrointestinal (GI) function and integrity, and may induce unfavourable shifts in the microbiota composition[6].

Recent research has highlighted the important role of the gut microbiota in mediating athlete health and performance via the microbiota-immune, the gut-brain and the gut-lung axes.



MICROBIOTA-IMMUNE AXIS

Our gut microbiota plays a fundamental role in the priming and functioning of our immune system[7]. Over half of all immunologically active cells in the body sit below the mucous layer of the gut, in the epithelium, known as gut-associated lymphoid tissue (GALT). GALT processes and responds to antigens from food and our gut microbes in a host-microbe exchange based on signalling molecules, but does not launch an inflammatory response. The microbiota supports the development and function of innate and adaptive immune cell function, including the balance between pro-inflammatory and anti-inflammatory cytokines. The tolerogenic interaction between the host and microbiota helps to keep the immune system alert. As such, we tolerate our commensal bacteria day-to-day, but when threatened by pathogenic agents, our body launches a coordinated immune response to identify and remove the threat. Those with a suppressed immune system are at risk of pathogens overriding these defences and contracting an infection more often. Conversely, an overactive immune system can also cause damage, as is seen for those with autoimmune diseases[8].

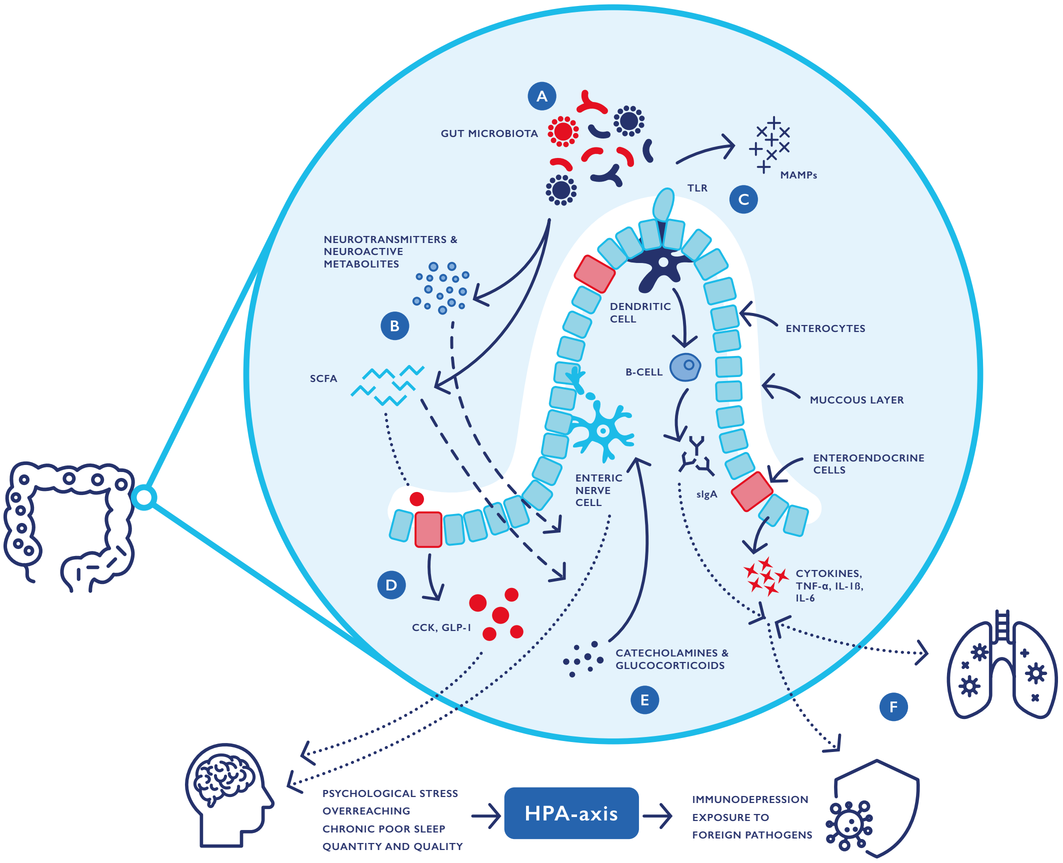
THE GUT-BRAIN AXIS

The gut-brain axis refers to the bi-directional communication that occurs between the gut and the brain[9]. Most of the information (~80%) relayed between these organs is fed from the gut to the brain. There are many lines of communication, including neural innervation, inflammatory and immune responses, enteroendocrine signalling and production of microbial metabolites. The most direct connection between the gut and the brain is a neural innervation via the vagus nerve. The gut is also innervated by the enteric nervous system (ENS), which controls many autonomic functions of the gut including contractions, secretions, and blood flow. The ENS is capable of functioning independently of the CNS and is therefore often termed the second brain.

The health of our GIT and microbiome can affect neurocognitive function and vice versa. The influence of the gut-brain axis on cognitive functions and psychological effects, includes altering responses to stress, changing behaviour states and has been used as a target for interventions in mental health conditions. Mental illnesses and neurological diseases have been closely related to dysbiosis in the gut microbiota. Contrastingly, dietary interventions with effects on the gut microbiota diversity have been related to cognitive and psychological benefits. The interactions in the gut-brain axis can be modulated by lifestyle factors such as diet, stress, sleep and medication. Exercise is associated with greater diversity in the gut microbiota and moderate exercise can reduce stress[4].

GUT-LUNG AXIS

Although seemingly distant organs, researchers are beginning to understand how health and functioning of the gut and lungs are linked. Dysbiosis of the GI microbiota has been associated with immune and inflammatory perturbations in the lungs[10]. The GI and respiratory tract, along with the urogenital tract, are linked through the common mucosal immune system. The mucosal immune system acts to identify, neutralise, and remove foreign antigens, promotes immunotolerance and maintains homeostasis for normal physiological processes. As these mucosal surfaces are continuously exposed to pathogens, they are highly vulnerable to infection. The GI microbiota has been shown to modulate immune function at distal mucosal interfaces, including the lungs[11]. Although not as dense as the gut microbiota, the lungs harbour their own specific, diverse microbial community. Dietary strategies to promote a healthy and diverse microbiota, more specifically to increase production of SCFAs, have begun to be explored in the prevention and management of inflammation and infection of the respiratory tract.



A. Microbes in the GIT ferment dietary fibre and polyphenols to produce SCFAs, neurotransmitters and other neuroactive metabolites. Dietary factors influence microbial composition and metabolite production. **B.** SCFAs, neurotransmitters and neuroactive metabolites enter systemic circulation. **C.** Microbe-associated molecular patterns (MAMPs) and antigens in food and microbes stimulate toll-like receptors (TLRs) and tolerogenic immune response. **D.** Enteroendocrine cells release hormones that regulate appetite and metabolism. SCFAs influence hormone production. **E.** Stimulation of hypothalamic-pituitary-adrenal (HPA) axis release catecholamines and glucocorticoids. Stress hormones trigger ENS, modify bacterial composition and may damage tight junction proteins and epithelial barrier. Chronic stimulation of HPA axis may depress immune function. **F.** Inflammatory markers and other immune signals relayed between the mucosal immune system.

We are now beginning to understand how our microbiota can be factored into these nutrition strategies. In this case series, we explore common scenarios that challenge the athlete's immune and/or GI systems. These include:

- Intensified training & competition
- Travel
- Stress and performance anxiety
- Exercise-induced GI symptoms
- Plant-based diets
- The older athlete

In this ebook, performance nutritionists Mhairi Keil and Lucy Wainwright provide examples of nutrition strategies they use to support their athletes.

Disclaimer: Nutrition strategies vary between individuals and the strategies shown here are examples only.

INTENSIFIED TRAINING AND COMPETITIVE EVENTS

We all know that regular exercise provides a multitude of health benefits, including reduced risk of acute illness and infection, chronic disease and stress, and improved mental health. Regular physical activity also appears to beneficially modulate the GI microbe population. However, intense training can transiently depress the athlete's innate and acquired immune function, possibly increasing the risk of pathogens overriding the body's immune defences, leading to infection, most commonly upper respiratory tract infections (URTIs).

Following a bout of heavy exercise, innate immune function is transiently depressed[12]. Lymphocytosis and neutrophilia occur following a bout of prolonged, strenuous exercise, proportional to the duration and intensity of exercise. Functional responses, including neutrophil degranulation, phagocytosis, and oxidative burst activity, and monocyte TLR expression, are diminished after >90 minutes of moderate to intense exercise. Innate mucosal immunity is also altered by very prolonged exercise (e.g., post-marathon). Secretory immunoglobulin A (SIgA) concentration decreases in saliva and tears, while secretion of saliva antimicrobial proteins including lysozyme, lactoferrin and α-defensin increases. Acquired immune functions, such as antigen presentation by monocytes or macrophages, immunoglobulin production by B lymphocytes, T lymphocyte cytokine production and proliferation are also reduced. This acute, exercise-induced immunodepression is likely mediated via increased circulating stress hormones (e.g., catecholamines and cortisol) and disruptions to the pro/anti-inflammatory cytokine profile. Periods of heavy training, or overreaching, have also been shown to depress cellular immune function and surveillance. This includes impaired redeployment of cytotoxic lymphocytes, reduced natural killer cell cytotoxic (NKCC) activity, and reduced T cell migration and proliferation. It is important to note, however, that a causitive link between these acute alterations to immune function (independent of other factors such as perceived psychological stress and under-nutrition) and increased risk of infection has not yet been established[12,13].

There is evidence to suggest that successive bouts of exercise, repeated on the same or consecutive days, prohibits restoration of innate and acquired immune indices[12]. Heavy training, or overreaching, may depress cellular immune function and surveillance. This includes impaired redeployment of cytotoxic lymphocytes, reduced NKCC, and reduced T cell migration and proliferation[14]. Again, the increased risk of infection associated with immunosuppression in response to heavy training remains contentious. It appears that overall, athletes experience similar rates of infection compared to the general population, however, some athletes appear to have greater susceptibility to recurrent infection impeding on training and competition. Moreover, it should be noted that training outdoors and inhaling cold, dry air can cause non-infectious inflammation of the upper airways, with symptoms mimicking that of an URTI[15].

The athlete's energy, macro- and micronutrient status are known to modulate immunoregulatory processes[16]. Adequate energy, specifically carbohydrate, is an essential fuel for immune cell activity, while amino acids (AAs) are required for synthesis of proteins such as immunoglobulins. Additionally, several micronutrient deficiencies, such as iron, vitamin D and zinc, have been linked with increased risk of illness and infection. Tolerogenic nutrients, such as anti-inflammatory- (i.e., vitamin D) or antioxidative- (i.e., vitamin C and E) nutrients, and nutrients targeting the microbiota (i.e., pre- and probiotics), may reduce the infection burden in athletes by improving immune tolerance and the ability to endure microbes[17].

CARBOHYDRATE

Carbohydrates provide fuel for immune cells. Timing of carbohydrate ingestion, rather than total carbohydrate intake, appears to exert immunomodulatory effects, associated with prolonged, strenuous exercise. Consumption during exercise to maintain blood glucose levels and blunt the release of stress hormones and cytokines, helps to attenuate exercise-induced immunodepression.

OMEGA-3 FATTY ACIDS

Long-chain omega-3 fatty acids eicosapentaenoic acid (EPA) and docosapentaenoic acid (DHA) have been shown to have anti-inflammatory and immunomodulatory activity. While the evidence is limited by the heterogeneity of studies, it appears that consuming >2g per day of combined EPA and DHA might have beneficial effects on inflammation, muscle soreness and immune function amongst athletes.

VITAMIN C

Vitamin C is highly researched for its antioxidant function and in particular, its effects on the onset, severity, and duration of URTIs. A Cochrane review presents moderate to strong evidence that vitamin C supplementation may prevent URTI. Vitamin C supplementation (250-1000 mg/day) reduced the incidence of URTI in athletes by ~50%[18].

VITAMIN D

Cholecalciferol-D3 plays an important role in innate and adaptive immune function, and its deficiency is linked with increased risk of URTI. Adequate sun exposure, consumption of vitamin D rich foods and supplementation of up to 4000 IU/day whenever necessary (during winter months and deficiency period) can help maintain vitamin D levels all year round. Although higher dose supplements are available, these are not advisable due to evidence of increased mortality in individuals with very high vitamin D levels (over 140 nmol/l).

ZINC

Some studies amongst the general population indicate that zinc may have preventative and therapeutic effects on common cold. Current consensus statements highlight that acute supplementation during intensive training periods might be beneficial, particularly for athletes who are prone to URTIs.

MICROBE-ACCESSIBLE NUTRIENTS

Microbe-accessible nutrients like prebiotics, dietary fibre and polyphenols are metabolised by the gut microbiota, fuel the growth of beneficial microorganisms, and promote diversity, resilience, and stability of the microbiota. As such, these nutrients may indirectly influence the microbiota-immune axis and support the host's ability to dampen an immune response and control infection at a non-damaging level. More specifically, polyphenols and their gut-derived metabolites are widely researched for their anti-inflammatory, antioxidant and immune-regulatory properties. Research shows that high-dose supplementation of certain polyphenols may be linked to reduced URTI in athletes. However, more research is needed to establish optimal dosing and the benefits of long-term consumption of polyphenols and gut-derived metabolites on athlete health and immune function.

DIETARY MICROBES

Dietary microbes, such as those found in fermented foods and probiotics, have been highlighted in recent consensus statements as an important dietary component to support athlete immune health. These microbes directly interact with the commensal gut microbiota (modulation of gut bacteria, competition with pathogens for binding sites and nutrients), reinforce gut barrier, interact with gut-associated lymphoid tissue and mediate immune signalling to a variety of organs and systems. Current research is mixed due to wide variation in strain, dose and duration of supplementation. However, there is moderate evidence to support daily supplementation of *Lactobacillus* or *Bifidobacterium* strains of probiotics containing at least 10^{10} live bacteria.

CASE STUDY

SUPPORTING A FEMALE GYMNAST TEAM DURING TRAINING CAMP

During a 5-day training camp, female athletes aged 17-25 years undertook 6-hour training days (2 x 3 hour sessions) with high intensity and load.

Prior to the camp, athletes were assessed for:

- Vitamin D and iron status via blood work
- Nutrition modification and/or supplementation provided as required
- Energy adequacy via food diary
- Sleep quality and quantity via questionnaire
- Hydration monitoring and sweat loss/fluid requirements
- Menstrual status assessment

The overall aim throughout the training camp was to maintain health and wellness, and minimise time lost to illness and recovery, whilst maintaining training volume, intensity and consistency.

The key objectives were:

- In training fuelling strategies
- Fruit and vegetable optimisation
- Sleep optimisation through nutrition factors in conjunction with Performance Lifestyle Psychology support
- Personal hygiene education

Time	Nutrition	Rationale
Wake-up	*Lactobacillus* or *Bifidobacterium* probiotic containing at least 10^{10} CFU	Reinforce gut barrier, interact with gut-associated lymphoid tissue and mediate immune signalling
Breakfast	Porridge made with jumbo oats, chia seeds, milk, raspberries and mashed banana. 1 glass of fresh orange juice 2000IU Vitamin D Turmeric shots	Boost prebiotic foods, increase carbohydrates to fuel training, hydrate prior to training, provide a quality source of protein fats and polyphenols
3 h training session	Sip on an electrolyte drink throughout 1- 1.5 hours into training consume a carbohydrate-rich snack such as a large banana and bag of dried fruit	Prevent excess fluid and electrolyte losses, and replenish liver and muscle glycogen stores to maintain training intensity
Lunch	Chicken and mixed vegetable pasta Probiotic-rich yoghurt Slice of pecan and banana bread	Replenish, recover and prepare for next training session
3 h training session	Sip on electrolyte drink throughout 1- 1.5 hours into training consume a carbohydrate-rich snack such as an oat and dried fruit energy bar	
Immediate post-training recovery	Pint of milk and some fruit e.g., apple, red grapes, 2 satsumas	Mix of protein, calcium and carbohydrates to support skeletal muscle and bone repair and adaptation
Dinner	Oven-baked salmon with pesto, roasted vine tomatoes, steamed greens with some oven-baked sweet potato wedges	Good source of protein (0.4g/kg or 20-25g per serve) to continue repair and adaptation whilst incorporating a good source of Omega 3 rich fats. A nutrient-dense, carbohydrate-rich option to replenish muscle glycogen stores which complements the antioxidants, vitamins and minerals obtained through the colourful range of vegetables.
Supper	Greek yoghurt or milk	Provide casein before overnight fast to support muscle repair and adaptation

Athletes were monitored via training output, daily health and wellbeing scores, sleep quality and duration, perceived muscle soreness, menstrual status and body weight. All athletes maintain training quality and intensity. No health issues were reported, nor were there any absences from training, reports of excess fatigue.

Dietitians and nutritionists are encouraged to ensure adequate overall macro- and micronutrient requirements are met when addressing athlete immune health during periods of functional overreaching. Supplementary nutritional strategies such as vitamin D3, vitamin C and *Lactobacillus* or *Bifidobacterium* probiotics are considered safe and low-risk options.

TRAVEL

Depending on the level of competition, many athletes may be required to travel for competition. This can place strain on the athlete's immune system by increasing exposure to foreign antigens or causing sleep disturbances. Athletes are at increased risk of contracting URTI or GI infections, as well as experiencing non-infectious GI symptoms.

INCREASED RISK OF INFECTION

Unfortunately, traveller's diarrhoea is common with international travel. When travelling for competition or events, it is important to note the level of risk in the travel zone and take on the necessary precautions. Traveller's diarrhoea can cause up to four days of incapacitation, significantly impairing nutritional intake, affect training intensity post-infection and presents the risk of post-infection irritable bowel syndrome (IBS)[12,19].

SLEEP DISTURBANCES

If travelling latitudinally, athletes will need to adjust their circadian rhythm. Altered circadian rhythm may present as disturbed sleep, in- or hypersomnia, as well as cognitive changes including decreased alertness, mood disturbances, and poor motivation. Appetite changes and GI distress may also occur. Researchers have observed changes in immune function associated with disrupted sleep patterns, possibly due to i) disturbances to hormone secretion, ii) general stress response, iii) cognitive reaction to loss of sleep[12,19].

Evidence taken from shift worker populations and those experiencing chronic jet lag has shown that sleep loss can also affect the composition of the microbiota. Sleep loss may induce dysbiosis through increased appetite, immune modulation or activation of the hypothalamic-pituitary-adrenal axis (HPA) and subsequent disruption of the intestinal barrier. The metabolites of bacteria that increase as a result of sleep loss may in turn lead to fatigue[20].

ALTERED BOWEL MOVEMENTS

Changes in bowel habits are common with travel, due to dehydration, lack of movement, and alteration of the type, timing and volume of food intake, including fibre intake[19]. Such factors typically increase colonic transit time resulting in constipation. In such a case, constipation should be reported to the medical team, and dietary and medicinal interventions (i.e., laxatives) should not be implemented without dietetic or medical supervision, respectively. Under dietetic supervision, foods and fluids may be used to provide relief for those with constipation.

CASE STUDY

ADVICE FOR THE TRAVELLING ATHLETE

Athletes are required to travel to training camps and competitions, often outside of the UK. Such travel demands can impact on the health and well-being of the athlete and their capacity to train/compete on arrival. It is important to have a travel strategy in place to negate the impact on the athlete. There are a number of areas to consider including, environment of the destination, number of time zones crossed, flight times/durations, impact on sleep, food provision and nutrient availability. Nutritional intake and timing play an important role in reducing symptoms of jet lag, travel fatigue and risk of illness.

4 weeks prior to travel	**Nutrition** Daily *Bifidobacterium* or *Lactobacillus* probiotic containing at least 10^{10} CFU.
Day of travel	**Nutrition** • Adjust mealtimes to destination times • Protein and fibre rich snacks e.g., Biltong, steamed edamame beans, boiled egg snack pots, yogurt & fruit, hummus, and carrot sticks. • Hydration/electrolyte tablets and fluids • Cool bag and bottle to fill with ice once through security, to store and transport nutritious meals and snacks • Chewing gum to maintain saliva flow rate and first line immune defence • For those prone to constipation following long haul flights, consider intake of foods with natural laxative effect e.g., prunes, kiwifruit, or flaxseed
	Hygiene • Pack antiviral hand foam and antibacterial wipes to wipe seating and eating area
	Sleep • Adjust sleep and meal times to destination time • Light exposure consideration during flight/on arrival • Eye mask to create darkness and aid sleep, rest and time zone adjustments • Travel pillow for neck support • Use of caffeine or avoidance of caffeine linked to sleep/nap times
Day of arrival	**Nutrition** • Mealtimes in line with destination mealtimes
	Sleep • Adjust sleep to destination time. Sleep and nap times/duration in line with jet lag strategy • Activity/training in line with light exposure requirements. Low level, low intensity, low skill level • Use of caffeine pre nap to wake up out of a nap, or post nap to stay awake if required. Avoidance of caffeine 4-5 hours pre bed
Days 2-4	**Sleep** • Progression of jet lag strategy depending on time zone changes and individual adjustment
Ongoing	**Nutrition** • Mealtimes in line with destination mealtimes

Athletes were monitored for nutrition and lifestyle strategy from four weeks prior to travel, during travel, arrival and for the duration of time spent for training and competition. The main aim was to reduce risk of infection, sleep disturbances and altered bowel movements. Maintaining the nutrition strategy, hygiene and sleep routines for athletes during travel, supports the normal functioning of the immune system, gut-brain axis and the GI system. No reports of loss of training time, health issues or fatigue were seen in this case-study.

The management strategies described above were successfully implemented to support gut and immune health during travel. Ensuring sufficient macronutrient and micronutrient intake, including adequate energy, vitamin C, vitamin D, and fibre consumption, as well as intake of probiotics. Dietitians and nutritionists are recommended to advise adequate fibre, hydration and maintenance of sleep and dietary routine. This allows for the adjustment of the circadian rhythm and maintenance of the gut microbiota symbiosis to support immune and gut function.

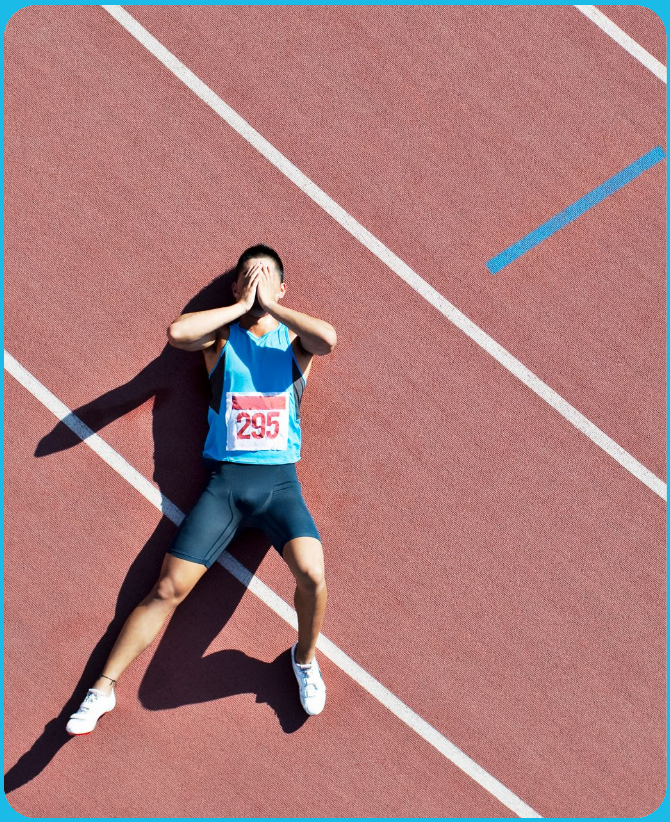
STRESS AND PERFORMANCE ANXIETY

Athletes, like all of us, experience many day-to-day external (e.g., relationship, financial, bereavement) and internal (e.g., self-criticism, social anxiety) psychological stressors, but also have the added pressure to deliver peak performance. Research has shown that professional athletes are likely to experience over 640 stressors that may increase susceptibility to development of common mental disorders[21]. Acute anxiety in preparation for a competitive event (commonly referred to as pre-race jitters) is experienced by athletes across all levels of competition and is generally considered normal and healthy. However, chronic and/or poorly managed psychological stress or anxiety can manifest as physical symptoms, including immunodepression, GI symptoms and sleep disruptions, that may be detrimental to performance.

Acutely, stressors activate the HPA and sympatho-adrenomedullary (SAM) axes to release catecholamines (adrenaline and noradrenaline) and cortisol to physically prepare the body to deal with the demands of incoming stress. Stress stimuli can be physical (i.e., exercise above 60% VO_{2max}) or psychological (i.e., anticipation of competition). The stress responses for physical and psychological stress share similar pathways and effector limbs and appear to present similar physical consequences of chronic dysregulation. Indeed, chronic stress can lead to dysregulation of the HPA axis and prolonged activation of the stress response. Chronic stress may increase the risk of cognitive and metabolic comorbidities and has also been associated immunosuppression. Chronic stress resulting from excessive training load and/or inadequate recovery is estimated to afflict between 20-60% of athletes[22]. To date, the effect of chronic psychological stress on immune parameters as an underlying mechanism for risk of illness and infection has not been systematically investigated in athletic populations. One study, however, has shown that in an Olympic athletic population, symptoms of depression and higher perceived stress were significantly associated with illness resulting in limited training or competition[23].

GI symptoms may also occur as a result of dysregulation of the HPA and gut-brain axes. For example, sustained activation of the HPA axis and an altered microbial profile has been demonstrated in those with IBS, compared with healthy control[24]. Likewise, severe psychological stress or anxiety brought on by anticipation of competition may present with GI symptoms, including poor appetite, poor tolerance to food and drinks, or altered bowel movements, such as urgent bowel movements, loose stools or diarrhoea. Acute dietary strategies such as small, frequent meals, low fermentable dietary fibre intake, and focus on sweet and palatable foods can be implemented to ease symptoms.

Both GI and immune perturbations that occur as a result of stress, may be mediated via the gut-brain axis. As a result, researchers have investigated the gut as a target organ for managing stress and anxiety by dietary interventions. Diets high in plant-based foods, such as the Mediterranean diet, have been linked to beneficial microbial profiles and reduced symptoms of anxiety and depression[25-27]. Clinical studies have also linked pre- and probiotics (*Lactobacillus* and *Bifidobacterium*) to improved anxiety symptoms[28], specifically amongst athletes[29]. On the other hand, cognitive focused stress management strategies, such as cognitive-behavioural coping therapy CBT, breathwork and meditation, might help to relieve GI symptoms via the gut-brain axis.



CASE STUDY

OLYMPIC DISTANCE TRIATHLETE WITH PERFORMANCE ANXIETY

Our athlete in this case study is a sprint/Olympic distance triathlete with a history of performance anxiety. Symptoms of anxiety were first identified around competition at Junior level. The athlete has moved up to Senior racing and has been working with a performance psychologist to develop pre-race psychological strategies to control performance anxiety. Nutrition strategies have been developed in training and implemented into race day strategies to reduce GI disturbances associated with performance anxiety.

Time	Nutrition	Rationale
1-2 days prior	Reduce fibre consumption Avoid caffeine intake Minimise dairy for those sensitive to this Incorporate aspects of a low FODMAP diet Avoid high fat foods	Reduced fibre intake to reduce gastric bulk. Avoid caffeine to minimise caffeine stimulation of the gut and avoid adding a stimulant into an environment with increased adrenaline and heightened anxiety.
Race day	Use of liquid meals for those who struggle to take on board solids Use of white rice-based meals e.g., rice porridge	To reduce fibre intake and gastric bulk prior to the race.
Pre-race **7:30am** **8:00am** **9:00-10:30am** **10:45am**	Probiotic and morning monitoring Rice porridge with banana, white toast and jam, orange juice and/or decaffeinated coffee Carbohydrate electrolyte drink Carbohydrate gel post-swim warm up	Top up liver and muscle glycogens stores pre-race. Fluid and electrolyte intakes to ensure good hydration status at the start of the race.
Race start **11:00am**	Race nutrition as per individual plan	Individual tried and tested race nutrition strategy, adapted for different race conditions.

As previously discussed, pre-race jitters are normal and healthy, as the resulting stress response physically and mentally primes the athlete to deliver peak performance. The athlete described above has successfully implemented both cognitive and dietary strategies to manage performance-induced anxiety. The dietary strategies delivered optimal nutrition, particularly carbohydrate, to meet the demands of the race, while minimising GI symptoms.

EXERCISE-INDUCED GASTROINTESTINAL SYNDROME

Redistribution of blood flow and increased sympathetic drive during prolonged, strenuous exercise can alter the absorptive capacity of the gut. This can induce upper (belching, reflux, poor tolerance and nausea) and lower (flatulence, lower abdominal bloating and pain, cramping or urge to defecate) GI symptoms, and limit the delivery of exogenous carbohydrate to the working muscles[6].

REDISTRIBUTION OF BLOOD FLOW

During exercise, blood flow is redirected to the working muscles to deliver increasing oxygen and nutrient demands. Research has shown that >1 hour exercise at 70% VO_{2max} will reduce splanchnic perfusion by up to 80%[30]. Exercising in high temperatures or when dehydrated will reduced blood volume and further exacerbate hypoperfusion of the gut. Ischemic damage and erosion of epithelial cells as a result of oxygen and nutrient deprivation stimulates a local inflammatory response. Ischemia and the local inflammatory response damages multi-protein complexes and tight-junction regulatory proteins of the epithelium. Bacteria, bacterial endotoxins and other pathogenic agents can enter circulation via physical breaks in the epithelium, further exacerbating local and systemic inflammatory responses.

INCREASED SYMPATHETIC DRIVE

At the onset of exercise, there is an increase in circulation of stress hormones (i.e., cortisol and adrenaline). Gastric motility, gastric emptying and translocation of epithelial transporters is reduced, resulting in overall reduced GI functional capacity. This can lead to upper GI symptoms such as poor tolerance to food and drinks, belching and reflux, as well as lower GI symptoms as a result of nutrient malabsorption.

MECHANICAL FORCE AND SHEAR STRESS

Mechanical forces during exercise have also been highlighted as a possible contributing factor to such problems. The jarring, jolting and friction that occurs during running and similar load bearing activities, as well as the 'kinking' of the GI tract in the cycling position, is thought to induce or contribute to GI symptoms.

CASE STUDY

STRATEGIES TO MANAGE EXERCISE INDUCED GI SYMPTOMS

The management of GI symptoms in athletes is critical to enable them to perform at their best. The information in this section provides some advice for the assessment of and potential intervention for an athlete who presents with GI symptoms that only arise during training/competition when intensity and/or volume is high. It is important to recognise that clinical assessments and interventions may be required if symptoms are not deemed to be the direct result of exercise[31].

DIETARY & SYMPTOMS ASSESSMENT

- Monitor the type (upper or lower), timing (onset and progression) and severity of GI symptoms using a standard, validated questionnaire[32]
- Assess quantity and quality of overall diet, lead in diet and race nutrition
  - Fibre: total fibre load and type (fermentability, solubility)
  - Food form: solid or liquid, concentration
  - Gastric irritants: including caffeine and medications
  - Possible food intolerances: including FODMAPs, dairy or gluten
  - Planned vs nutritional actual intake
  - A combined food, training and symptom diary can be complemented to get an understanding of bowel movements and symptoms in relation to food intake and training.

OVERALL DIET

- Adjustment of fibre type/timing in relation to training.
- Establish, reduce and/or eliminate irritants and intolerances.
- Strategies to optimise gut health and GI barrier.

TRAINING

- Establish an individual athlete plan based on the findings from the assessments and race nutrition requirements. Gradual increases in carbohydrate intake during training to improve gut tolerance in relation to race day plan.
- Increases/adjustments in a progressive manner over 4-6 weeks depending on changes required and GI symptoms. Ensure at least 2 weeks of a steady state race day nutrition plan to build confidence and consistency in the plan. Nutritional requirements then need to be adjusted to account for a reduction in training during the taper week.
- Gut-training: for athletes requiring exogenous carbohydrates during the race, gut-training protocols can help to maximise absorptive capacity of the gut and minimise GI disturbances. This protocol challenges the GIT with excess food and fluid load and concentration. Up until 2 weeks prior, aim for 120% estimated carbohydrate requirements/ fluid volume.

PRE-RACE

- 48 hours prior: low FODMAP/low fibre and residue.
- Day of: Ensure optimal hydration. Drink in line with fluid and electrolyte requirements as part of pre-determined race day strategy to minimise over or under consumption.
- 3-4 hours prior: pre-exercise meal with low fibre, high carbohydrate.
- 2 hours prior: pre-exercise snack with low fibre, low protein, high carbohydrate
- Allow time to empty bowels when appropriate.

RACE NUTRITION

- The carbohydrate quantity (30-90g/hour) and form (e.g., liquid, solid or gel) will be determined by the length of the race, the intensity, the mode (e.g., swimming, running, cycling) and feeding opportunities within the race.
- Co-ingestion of glucose and fructose, especially when requirements are approaching or exceed 60g/hour, can maximize absorption of exogenous carbohydrate. Research has shown that the optimum ratio of glucose : fructose is 2 : 1 (or even less).
- Fluid requirements will be determined by individual sweat losses and environmental conditions in addition to the considerations above. Therefore, fluid volume and composition (e.g., carbohydrate and electrolytes) should be pre-planned.
- In short duration events where race fuelling is not required, individuals may benefit from having some food in the GI system, to help maintain blood flow to the tissue and minimise potential reperfusion injury.

POST-RACE NUTRITION

- Replenish energy, carbohydrate, protein and fluid in small, regular and easily digestible formats as this is when GI symptoms can be exacerbated.
- Minimise irritants immediately post-race, e.g., dairy, spicy.

An understanding of the type and severity of symptoms, daily, pre-race and race day nutrition strategies, and likely underlying causes of GI symptoms during exercise are required to inform nutrition strategies[31]. It is unlikely symptoms will be eliminated. Rather, practitioners should focus on minimising symptoms while maximising nutritional intake to support performance.

PLANT-BASED DIET

In recent years, diets that predominantly or exclusively include plant foods have gained widespread popularity. The term 'plant-based' is recognised by health care professionals to describe diets that mainly consist of fruits, vegetables, grains, nuts, seeds, herbs, and spices, with or without animal and animal-derived products. In consumer media, however, the term is typically associated with vegan and vegetarian diets. There are many drivers behind this trend, including animal welfare, climate protection and purported health benefits.

It is widely accepted that high consumption of plant foods confers several health benefits including reduced risk of metabolic diseases, mental health conditions and some cancers. Many of these benefits are mediated directly or indirectly via the gut microbiome. Research has shown that consumption of at least 30 unique plant foods per week increases the diversity of the gut microbiota, rather than the categorical diet (omnivore, vegetarian, vegan etc)[33]. Vegan, vegetarian and other 'plant-based' diets containing intact plant cell walls, larger food particles and with minimal processing have low nutrient bioavailability. While these dietary features increase the risk of certain nutrient deficiencies, there is increased delivery of microbe-accessible nutrients to the lower GI system, thus enriching the microbial community. As such, those with high fibre and polyphenol intake typically have concentrations of beneficial bacteria including *Ruminococcus*, *Eubacterium rectale*, and *Roseburia*, *Lactobacillus* and *Bifidobacterium*, and increased production of SCFAs[34].

Plant-based dietary patterns have anecdotally been associated with enhanced athletic performance, at least partly due to the proliferation of social media. While there are indeed a multitude of benefits associated with increased plant intake, there is currently insufficient evidence to support enhanced performance with a vegan or vegetarian diet beyond that of a nutritionally equivalent omnivorous diet. Notably, a poorly designed vegetarian or vegan diet may increase the risk of macro- and micronutrient deficiencies, thereby impairing athletic performance. Nutrients at risk include omega-3 fatty acids, vitamin B12, vitamin D, iron, zinc and calcium. Endurance and ultra-endurance athletes may also struggle to meet overall energy requirements[35].

CARBOHYDRATE

Vegan diets are typically high in carbohydrates including dietary fibre and resistant starch derived from pulses, legumes and whole grains. High consumption of non-digestible fibres may promote early satiety and/or GI discomfort. Fibre intake should be periodised throughout the day, with low-fibre carbohydrates, such as pasta, rice, and peeled vegetables, prioritised prior to training sessions to ensure adequate carbohydrate levels while minimising GI discomfort.

PROTEIN

Most plant sources of protein have an incomplete AA profile and lower Branched Chain Amino Acid (BCAAs) content than animal proteins. Plant foods with complete AA profiles include soy (edamame beans, tofu, tempeh or soymilk), quinoa, buckwheat, chia seeds, and amaranth. Including a variety of pulses and grains also helps to achieve a complete AA profile. Protein sources should be prioritised at each meal, with the goal to include 20-30 g per main meal. Those with high protein requirements are encouraged to increase frequency of protein intake, rather that increasing the protein bolus in a single meal. Consumption of greater amounts of protein in the evening helps to achieve a positive net protein balance before entering the overnight fast. Protein supplements including soy, pea, rice or hemp may be necessary to achieve protein goals.

FATS

Vegan diets are generally lower in total and saturated fat content while being higher in n-6 fatty acids when compared to typical western diets. The reduced saturated fat consumption in vegan diets may be beneficial to overall health as some evidence suggests that saturated fats may have pro-inflammatory effects. On the other hand, consumption of omega-3 fatty acids (DHA and EPA in particular) is associated with beneficial outcomes like anti-inflammatory effects and enhanced immune function. Although seafood is the most common source of n-3 fatty acids, those on vegan diets may optimise their omega-3 fatty acid intake by consuming flax seeds, walnut, chia seeds and micro-algae oil supplements.

VITAMIN B12

Vitamin B12 is primarily found in meat and dairy products, meaning that those following vegan diets are at a higher risk of developing a deficiency. Vitamin B12 is essential for DNA synthesis, functioning of the nervous system and production of red blood cells and vegans are advised to consume yeast extracts, nutritional yeast, B12 fortified foods and/or supplements to reach the 2.4 μg/ day recommended daily intake.

VITAMIN D

Vitamin D plays a vital role in bone health, calcium absorption and supports immune function. Vitamin D3, also known as cholecalciferol is a more bioavailable form that can be synthesised on exposure to sunlight or derived from animal foods and some lichens. Vitamin D2, ergocalciferol, is a less bioavailable form of vitamin D that is found in certain mushrooms. Those on vegan diets can supplement their diet with cholecalciferol (plant-based supplements available) to meet their RDI (10 μg/day), especially in winter months.

CALCIUM

Calcium is essential for maintaining bone health, vitamin D metabolism, muscle function and various metabolic processes in the body. Vegans typically consume less calcium than omnivores, possibly due to the lack of dairy, a major source of calcium, in their diet. To meet the recommended daily intake (RDI) of 1000 mg/day for calcium, vegan athletes may be advised to consume plant-based sources of calcium like beans, leafy greens and calcium-fortified vegan dairy alternatives.

IRON

Vegan athletes are at high risk of iron deficiency, due to low bioavailability of dietary iron (non-haem iron in conjunction with high phytate and tannin content) and increased iron requirements. Providing a good source of vitamins C and A can help to maximise absorption. Conversely, consuming tea, coffee or red wine with meals will limit bioavailability of iron. Iron status should be monitored, and supplementation may be considered for those prone to deficiency and anaemia.

CASE STUDY

29-YEAR-OLD RECREATIONAL MALE CYCLIST TRANSITIONS TO VEGAN DIET

A 29-year-old male cyclist recently transitioned to a vegan diet, after having sustained a vegetarian diet for the past 6 years. His training schedule included a 60–90-minute morning session on weekdays, with an additional 2-3 hour ride on the weekend. Within two weeks of adopting a vegan diet, the cyclist began to experience moderate to severe (5-8 out of 10-point visual analogue scale (VAS)) GI symptoms occurring daily, including cramping, bloating, diarrhoea (3-5 times per day). These symptoms, especially urgency, would worsen during exercise, and consequently interrupting training sessions. The cyclist also noted meals were becoming boring and repetitive. He was having difficulty adhering to his current diet plan and was struggling to achieve adequate energy intake.

A dietary assessment showed that the cyclist's symptoms were associated with increased and frequent intake of fructose in excess of glucose (sourced from agave syrup and dried fruit) and/or galacto-oligosaccharides and fructo-oligosaccharides (sources from lentils, onion and garlic). The aim was to reduce the incidence and severity of GI symptoms while maintaining training load and performance.

	Diet assessment	Recommendations	Rationale
Breakfast	Porridge oats made up with soy milk (vitamin D and calcium fortified), topped with agave syrup and mixed seeds Soymilk latte with 2 shots	Swap agave syrup for maple syrup or mashed banana Add chia seeds to porridge	Maple syrup contains less fructose than agave syrup and is considered low FODMAP. Chia seeds are high in calcium, omega-3 fatty acids and complete protein
Morning snack	Muesli bar with dried fruit and an apple	Swap to fruit-free muesli bar Include low-FODMAP fruit such as orange, strawberries, yellow-green banana	Dried fruit, including sultanas, dates, cranberries and apricots, are high in fructans, fructose and/or sorbitol, and are easy to over-consume.
Lunch	Rice and dahl (red or brown lentils, onion, garlic +/- potato, carrot, pumpkin)	Swap lentils at 1 or more main meal for firm tofu, tempeh, edamame beans, or mycoprotein. Increase diversity of grains and cereals e.g., quinoa, corn, wild rice (if fits with daily fibre consumption)	Reducing frequency of consumption of lentils will reduce GOS load Increasing the variety of protein and grain sources for complete amino-acid profile and increase enjoyment.
Afternoon snack	2 slices whole wheat toast with agave syrup and margarine with a handful of dried fruit and nuts (almonds, walnuts, cashews, dates, apricots)	Consider swapping to low FODMAP bread with nut butter or strawberry jam	Reduce fructan load Nut butter adds healthy fats and protein, and helps to achieve energy requirements
Dinner	Similar to lunch or lentil Bolognese (lentils, mushroom, onion, garlic, carrot, celery, tomato)	Changes as per lunchtime meal Resources for vegan diets provided to increase variety	
Dessert	Homemade bliss balls made with dates, oats, coconut, agave syrup and almonds	Suggest alternatives such as homemade smoothie with vegan protein powder or silken tofu, flavoured soymilk or chia pudding. Adapt homemade bliss ball recipe to oats, nuts, maple syrup, coconut/cinnamon.	Reduce fructan/fructose load and increase variety and increase overnight net protein balance. Adapt homemade bliss ball recipe to reduce dried fruit/agave syrup and add protein powder if required to increase protein consumption.
Supplements	1000 IU vitamin D3	Increase to 2000 IU D3 Consideration of vegan B12 vitamin and omega-3 supplement Blood work and supplementation of iron if necessary	Prevent at-risk nutrient deficiencies

The athlete continued to record dietary intake and associated symptoms on 10-point VAS scale before and after meals, and before and after training. After 2 weeks, episodes of diarrhoea reduced to 3-4 times per week, and severity of symptoms reduced to mild to moderate (range 0-4/10 on VAS scale). Monitoring of at-risk nutrients via dietary records and biochemical analysis, and appropriate supplementation, is required for long-term monitoring.

THE MASTERS ATHLETE

"Masters athlete" is a term used to describe the "ageing" athlete who regularly trains and competes in a given sport. Over the past few decades, there have been increasing numbers of high-level recreational athletes, as well as retired elite athletes, who are competing well into their 60s and 70s[36]. As with the general population, there are specific nutritional requirements that need to be addressed with advancing age amongst masters athletes. Further consideration also needs to be given to the nutritional demands brought on with training and competition.

Both endurance capacity and muscular strength decline with age[37]. Cardiovascular fitness, as measured by VO_{2max} , peaks during the third decade of life and steadily declines thereafter, likely as a product of reduced maximal heart rate and cardiac output. Similarly, muscle size and strength peak around the age of 25-30 years and begins to decline in middle age (~50 years). It appears that muscle loss is associated with i) overall decrease in muscle fibres, ii) reduction in muscle fibre size, and iii) decreased fibre recruitment due to loss of motor neurons.

Changes to our microbiota and immune function also occur as we age[38]. Over the course of our lifetime, the gut microbiota evolves in response to different circumstances. As infants, the mode of delivery, whether we were breast or formula fed, and when we were weaned and onto which foods, all shape our early microbiota profile. On the other end of the spectrum, we see lower numbers of important SCFA producers, and more protein breakdown (proteolysis) in elderly populations. There is also an age-related decline in immune function, characterised by a decline in T-cell function, reductions in B-cells and natural killer cells, impaired antigen presenting and chronic inflammation. It should be noted that age-associated decline in immune and GI function have not been systematically researched amongst masters athletes. Much like anabolic resistance, age-related decline in immune function appears to be mitigated by regular participation in physical activity.

NUTRIENTS TO NOTE

Protein

Given the widely recognised decrements in skeletal muscle mass with age, protein intake and daily distribution is particularly important for masters athletes. Generally, a daily intake of ~1.2 g/kg body mass/day is recommended for masters athletes. This value may be higher for those looking to gain muscle mass or for endurance/ultra-endurance athletes. Intake of ~0.4 g/kg BM of high-quality protein (e.g., meat, dairy, eggs or soy) immediately after training appears to promote skeletal muscle synthesis. Daily protein distribution is also important, as 20-30g boluses consumed 3-4 times per day helps to promote a positive net protein balance.

Vitamin D

With age we experience loss of bone minerals and decreased ability to synthesise vitamin D from sunlight exposure. As previously discussed, vitamin D is essential for bone growth and mineralisation, immune response and muscle function. These important functions in conjunction with increased requirements and decreased capacity for synthesis, make vitamin D a key nutrient to note amongst masters athletes.

Calcium

In addition to vitamin D, calcium is essential to attenuate age-related bone mineral loss, particularly for female athletes.

Hydration

Older adults may experience decreased thirst perception, so a hydration plan should be implemented for training and events where excessive fluid losses are experienced.

Live microbes and microbe-accessible nutrients

As mentioned above, gut microbial diversity has been shown to decrease with age. Consumption of microbe-accessible nutrients, particularly prebiotics, have been shown to increase microbial diversity and attenuate immunosenescence in older adults, while probiotics may help to increase populations of beneficial bacteria.

CASE STUDY

74-YEAR-OLD FEMALE RACE WALKER

In this case study, we review the dietary strategies used to support a 74-year-old female race walker, who after a body composition assessment offered at her local gym, is seeking advice to help regain muscle mass. Six years prior, the athlete received the same bioelectrical impedance analysis. Comparison of results show the athlete gained 3.0 kg of body fat, while losing a total of 1.1 kg / 5.5% of skeletal muscle mass. The athlete also remarked on a decrease in training intensity in the past 6 months. With her next event in 2 months (10 km race), the athlete is seeking to review her performance nutrition strategy and prevent further muscle loss.

68 years	→	74 years (+ 6 years)
165 cm	→	165 cm
65.7 kg	→	67.6 kg (+1.9 kg)
32.3% / 21.2 kg body fat	→	35.4% / 24.2 kg (+3.1% / +3.0 kg)
19.9 kg SMM	→	18.8 kg (- 1.1 kg)

Assessment	Advice
Daily macronutrient nutritional adequacy	
1. Energy: Athlete is meeting energy requirements on heavy training days, and meeting or exceeding requirements on rest and light training days. Excess energy derived from carbohydrate on rest and lights days and carbohydrates, fats and occasional alcohol on weekends. **2. Carbohydrate:** Athlete is meeting or exceeding carbohydrate intake needs on moderate (60-90 minute moderate walks) training days (5-7 g/kd/day) and meeting carbohydrate requirements for heavy (150 minute moderate runs) training days (6-10 g/kg/day). **3. Protein:** Athlete is meeting daily protein requirements of 1.2g/kg/day (~95 g), and often exceeding this intake on weekends. **4. Fats:** Total fat intake is contributing less than 20% overall energy intake, occasionally contributing more on weekends.	**1.** Periodise energy intakes to account for different volume/intensity of training across the week. For example increase energy consumption on higher volume/intensity days and reduce consumption on lighter/rest days. **2.** Reduce carbohydrate intake on moderate days as appropriate, and aim towards the lower end of the range on heavy training days. **3.** Aim for a higher total daily protein intake of 2-2.2g/kg/day to help gain lean mass. Ageing muscle is less sensitive to protein and requires higher intake to stimulate muscle protein synthesis. Focus on individual meal/snack protein portions of 0.4g/kg body weight. **4.** No changes to overall fat intake required.
Micronutrient nutritional adequacy	
Possible suboptimal intake of Vitamin D.	Increase intake of vitamin D foods, including oily fish, mushrooms and fortified dairy products. Suboptimal levels are unlikely to be corrected by foods alone. Ideally get blood work completed to establish current vitamin D levels and then supplement as required.
Timing of nutrition	
Recovery nutrition not consumed until 60-90 minutes after training. Generally, a high carbohydrate snack with inadequate protein (i.e., <20 g) (e.g., 3 slices honey or jam on toast, or orange juice and fruit flavoured yoghurt). Next meal consumed within 2-3 h post training. Protein distribution skewed towards evening meal (>35 g). Inadequate protein intake in the morning and post-training. Protein quality high with mix of animal (chicken, fish and eggs), dairy (milk and yoghurt) and plant proteins (wholegrain).	Consume recovery meal or snack within 60 minutes of exercise. Aim for ~65 g carbohydrate and 20-30 g protein. Aim for at least 20 g protein at breakfast, lunch and recovery meal, with more (~30 g) in the evening before overnight fast.
Food source diversity	
Minimal diversity with repetition of same breakfast every morning and 3-4 meals on rotation for lunch/dinner each week.	Encourage greater inclusion of plants within and between categories of fruit, vegetables, nuts, seeds, wholegrains, herbs and spices. Provide recipe ideas and help with meal planning to encourage greater food variety.
Nutrient supplementation	
Not currently consuming nutritional supplements	Vitamin D requirements to be determined based on a blood test and time of year. Higher intake of omega 3 fatty acids to optimise muscle protein synthesis. Use of an omega 3 supplement if dietary consumption of this nutrient is low Consider the use of a low dose creatine supplement to help reduce any muscle loss and support training Review of bone trophic nutrients e.g., calcium, vitamin K, magnesium, phosphorus, boron Consider pre- or probiotic (*Bifidobacterium or Lactobacillus*) supplement to support beneficial microbial modulation

The presented case study describes nutritional strategies used to support a 74-year-old female race walker, with an emphasis on macro- and micronutrient intake to optimise muscle, bone, immune and gut health. Given the limited body of evidence to inform nutritional practices in the ageing athletic population, many of the nutrient estimates are drawn from studies conducted amongst young athletes. As such, ongoing monitoring of intake, body composition, training intensity and biochemical nutrient status is needed to inform adjustments. Regular liaising with the athlete's physician should also be considered.

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