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ARTICLE

Nutrition for master athletes: from challenges to optimisation strategies

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Abstract – Master athletes are genuine examples of successful ageing thanks to their capacity of maintaining a high level of sports performance during their entire life. Within the last decade many studies have focused on the evolution of performance in many sports with ageing, as well as on the training modalities to reach such performance. On the contrary, there is a paucity of data on the nutritional habits of master athletes and the question of whether they need to adapt their nutrition to the ageing process remains unsolved. This is within this context of the optimisation of nutrition for master athletes that this review stands. The aim is to identify the potential nutritional challenges encountered by master athletes and how to handle them through adapted nutritional strategies. Given the lack of data specific to master athletes, studies including master athletes are considered as a priority, though we also make inferences based on nutrition for young adults and perturbations induced by ageing in non-athletic populations. The first part of this opinion paper tackles the first challenge faced by master athletes which is the gradual reduction in energy intake with ageing. The second challenge is the anabolic resistance and the need for increased protein intake. The third nutritional challenge we present is the episodes of metabolic crisis master athletes may face throughout life. Finally, we gather the main nutritional recommendations for master athletes and suggest the next stage of research.

Key words: ageing, nutrition, protein, muscle mass, performance, diet

Résumé – Nutrition pour l'athlète master : challenges et stratégies d'optimisation. Les athlètes master représentent de véritables modèles de vieillissement réussi grâce à leur capacité à maintenir un haut niveau de performance durant toute leur vie. Au cours des dix dernières années, de nombreuses études se sont penchées sur l'évolution des performances sportives avec l'âge et sur les modalités d'entraînement permettant d'atteindre de telles performances. À l'inverse, peu de données existent sur les habitudes nutritionnelles des athlètes master et sur la nécessité potentielle de modifier leurs apports nutritionnels avec l'âge. C'est dans le contexte de l'optimisation des apports nutritionnels de l'athlète master que s'inscrit cette revue. Le but sera d'identifier les challenges nutritionnels imposés par l'avancée dans l'âge et la manière d'y faire face par l'intermédiaire de stratégies nutritionnelles adaptées. Les études incluant les athlètes master seront considérées en priorité. Néanmoins, étant donné le manque de données scientifiques spécifiques aux athlètes masters, les données abordant la nutrition des jeunes adultes et celles des perturbations induites par l'âge chez des populations non sportives seront également incluses. La première partie de cette revue d'opinion s'intéressera au premier challenge auquel l'athlète doit faire face : la réduction progressive de l'apport énergétique avec l'âge. Le deuxième challenge sera la résistance anabolique développée avec l'âge et le besoin d'augmenter l'apport en protéines alimentaires. Le troisième challenge nutritionnel concernera les épisodes de crise métabolique que l'athlète master peut avoir à surmonter au cours de sa vie. Enfin nous rassemblerons les principales recommandations nutritionnelles pour optimiser la performance des athlètes masters.

Mots clés : vieillissement, alimentation, protéine, masse musculaire, performance, nutrition

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1 Introduction

We are attending a global ageing of the population at National, European and world levels. For example, on the 1st of January 2019 the French population (in mainland France) included 66.9 million people with 26% (17.5 million) aged above 60 years. This portion of the French population does not stop to rise. The increase of the number of people aged above 75 is the greatest compared to all other age groups; in 20 years, their number has increased by ~2 million corresponding to a 32% increase. Meanwhile, the number of people aged under 20 years only increased by 2.7% (INSEE, 2019). The ageing of the population is accompanied by an unstoppable decline of physical capacities, which is accentuated by a sedentary lifestyle (Porter, Vandervoort, & Lexell, 1995). Indeed, a progressive deconditioning due to low physical activity is reported to accelerate the ageing process through the rapid alteration of muscular, cardiorespiratory and metabolic capacities (Wright & Perricelli, 2008). When the decline in intrinsic physical capacities such as muscle force and maximal oxygen uptake is initiated, daily life activities become an increasing burden, are painful and require more energy. This lifestyle gradually leads to conditions classically associated with ageing such as sarcopenia (*i.e.* loss of muscle protein mass and loss of muscle function), osteoporosis, obesity and cardio-vascular pathologies (Biolo, Cederholm, & Muscaritoli, 2014; Rolland *et al.*, 2008). The ageing of the population is generally accompanied with a gradual increase in public heath expenses and warrants the search for new strategies to promote healthy and active ageing.

Certain people such as master athletes consider ageing differently. Based on a recent review, master athletes (≥ 40 years old) can be defined as healthy subjects who train regularly throughout life and strive to maintain their performance level as long as they can (Lepers & Stapley, 2016). In the last decade, master athletes have been subjects to numerous research studies aiming to understand their extraordinary capacity to maintain physical performance (Bernard, Sultana, Lepers, Hausswirth, & Brisswalter, 2010; Lepers & Cattagni, 2012; Lepers & Stapley, 2016; Tanaka & Seals, 2008). It has also been observed an increase in the participation of master athletes in sporting competitions (mainly in endurance sports such as long distance running and triathlon) and an improvement of records in all master's age groups (Nikolaidis, Zingg, & Knechtle, 2017). Master athletes are thus considered as genuine examples of successful ageing. The observation of their lifestyle habits (*i.e.* training, diet, sleep) and their physical capacities also represents a valuable resource to better understand the ageing process and strategies for healthy ageing (Lazarus & Harridge, 2017; Louis, Hausswirth, Easthope, & Brisswalter, 2012; Louis, Vercruyssen, & Bernard, 2018; Sultana *et al.*, 2012).

With this in mind, this article aims to analyse the requirements for healthy and active ageing. We focus our analysis on nutritional strategies (*i.e.* with a food first approach) that are considered as key determinants of any form of physical performance. Given that limited data is available on the impact of nutrition in healthy ageing people practicing exercise regularly, a particular attention is brought to the nutritional challenges that master athletes may face to stay competitive. We begin our analysis with an insight into their nutritional habits and energy balance. We follow with the effect of ageing on muscle metabolism with an emphasis on nutritional strategies to overcome anabolic resistance. We then highlight key moments in master athletes' life during which nutrition must be optimised. Finally, we close by providing practical nutritional recommendations to optimise performance of master athletes and we suggest the next stage of research.

2 Dietary habits and energy balance of master athletes

It is well established that a balanced diet is paramount to stay healthy and is even more important for athletes whose dietary needs are increased (Burke & Hawley, 2018). Physical activity classically leads to an increase in energy expenditure, which must be sustained through a subsequent increase in energy intake. This balance between energy expenditure and energy intake must be maintained at all times to guarantee normal physiological functioning. The maintenance of energy balance also allows the athletes to recover well post training sessions, adapt to the training load and maintain their body composition (Loucks & Thuma, 2003). On the contrary, a persistent caloric deficit (energy expenditure > energy intake) occurring for instance when food consumption is not sufficient may gradually lead to muscle mass loss, weakening of the immune system, and potential reduction in training intensity (Mountjoy *et al.*, 2014).

Within these conditions, a balanced diet must provide enough energy (from macronutrients: carbohydrates, fats and proteins) to allow physical exercise while avoiding maladaptation to training such as overreaching and injuries. More precisely, maintaining a sufficient energy availability is recommended to facilitate adaptation to training, maintain body composition and stay healthy. A substantial amount of research has been conducted to better inform the dietary needs of athletes engaged in different sporting events (Burke & Hawley, 2018). In contrast, there is a paucity of published data addressing the dietary requirements of master athletes (Rosenbloom & Dunaway, 2007). However the physiological changes associated with ageing might require modification/adaptation in the master athletes' diet. For example, maintaining a balanced diet adapted to the demands of the sport may become a challenge with ageing. The main difficulty faced by master athletes may be a reduction in spontaneous energy intake which can lead to energy deficit and even deficiencies in essential macro- and micronutrients (*i.e.* vitamins and minerals). This decrease in energy intake has been reported in dietary surveys conducted mainly with sedentary ageing people (Morley, 2000). It was reported that one third of adults over 50 years of age fail to meet the recommended daily allowance (RDA) of 0.8 g/kg/day for protein (Wolfe & Miller, 2008), yet an important macronutrient to preserve lean body mass. While the risk of inadequate energy intake exists with ageing, to date there is no clear evidence of insufficient energy intake in master athletes. To date, the majority of studies having investigated the dietary intake of master athletes compared to age-matched sedentary people have reported higher energy intakes for master athletes. Butterworth, Nieman, Perkins, Warren, & Dotson (1993) reported a higher energy intake (more calories) in master female athletes compared to sedentary women of the same age (67 to 85 years). Beshgetoor & Nichols (2003) reported an average energy intake of 2079 and 2001 kcal/day in female master athletes (runners and cyclists) taking or not taking dietary supplements (mainly vitamin and minerals), respectively, on a regular basis. It was concluded that the energy intake was greater for the master athletes of this study than the energy intake (1632 kcal/day) reported by the US Department of Agriculture for non-athletic women of a similar age (50–59 years). In another study conducted in Europe, Chatard *et al.* (1998) found similar results in a group of 23 master athletes (mean age: 63 years) practicing mainly aerobic activities (cycling, running, swimming, tennis and walking) for an average of 2.6 h per day. On average, the daily energy intake was higher (+24%) than the RDA at the time. In this study, the macro nutrient intake of master athletes was also higher than the RDA for non-active elderly people, with +46% for protein, +34% for fat and +13% for carbohydrates. The higher energy expenditure related to daily sport activity increased energy intake up to values close to the RDA for young athletes. Recently, using dietary recall, Doering, Reaburn, Cox, & Jenkins (2016) investigated the post-exercise dietary intake of master (mean age: 57.7 years) *vs.* young (mean age: 24.4 years) Australian triathletes. Overall, master triathletes consumed less energy post-exercise (22.7 kJ/kg) than young triathletes (37.8 kJ/kg). In master triathletes, post-exercise carbohydrate intake was also less (0.7 g/kg) than recommended for optimal recovery (1.0 g/kg) and less than their young counterparts (1.1 g/kg). Post-exercise protein intake also tended to be lower in masters (19.6 g) compared to young triathletes (26.4 g). Taken together, studies conducted with recreationally trained old populations compared to sedentary people of the same age suggest that regular physical activity can lower the risk of nutritional deficit with ageing. However, the recent results from Doering, Reaburn, Cox *et al.* (2016) including endurance trained subjects show that master athletes are still at risk of inadequate energy intake, which can affect their recovery capacity. Within this context, additional research is warranted to better understand the potential modification of energy demands of various physical activities with ageing. The gold standard technique of doubly labelled water should be prioritised, followed by the analysis of respiratory gas exchanged during the activity to obtain more accurate data compared to heart rate based calculations or physical activity logs. Gas exchange analysis and particularly the kinetics of respiratory exchanges ratio can also inform on substrates oxidised during the activity and potential alterations of metabolism with ageing.

A gradual decrease in resting metabolic rate (RMR), *i.e.* amount of energy expended at rest and for daily life activities might also explain the reduction in energy intake with ageing. RMR accounts for ~60–75% of total daily energy expenditure and its decline could alter the capacity to regulate the energy balance. A decrease of 13–20% in RMR is generally reported between the age of 30 and 80 years in non-athletic populations, with men exhibiting a greater decrease and an earlier onset in the decline of RMR (Poehlman *et al.*, 1992). Decreased lean body mass and reduced skeletal muscle protein turnover are the main factors responsible for this gradual decline in RMR with ageing (Wilson & Morley, 2003). Interestingly, regular physical activity and adequate energy intake have the potential to maintain RMR with ageing, as significant positive correlations have been reported for both males (van Pelt, Dinneno, Seals, & Jones, 2001) and females (Van Pelt *et al.*, 1997). In these studies, males (63 years) and females (58 years) regularly trained mainly in endurance for 7.6 h per week, and their average energy intake was 2573 kcal/day (with 4.7 g/kg/day for carbohydrates, 0.9 g/kg/day for fat and 1.2 g/kg/day for protein) and 1995 kcal/day (with 4.9 g/kg/day for carbohydrates, 1.0 g/kg/day for fat and 1.3 g/kg/day for protein) for males and females respectively. Even though the macronutrient intake was not optimal in these studies, the results suggest that master athletes who are able to maintain a high training volume and high energy intake with age could maintain RMR and thus better regulate their metabolism, dietary intake and body composition.

3 Anabolic resistance with ageing

Skeletal muscles have plastic properties that allow a constant remodelling of their structures through acute and chronic mechanisms of protein synthesis (anabolism) and breakdown (catabolism). The equilibrium between these two mechanisms determines whether muscle tissue grows (hypertrophy) or decreases (amyotrophy) (Burd, Tang, Moore, & Phillips, 2009). For resistance athletes as well as endurance athletes, the remodelling of muscle tissue is essential to eliminate protein damaged during exercise and stimulate the resynthesis of new functional proteins. It is reported that muscle proteins turn over at a rate of 1–2% per day, equating to 500–600 g of muscle that is broken down and resynthesized over 24 h, with an entire renewal of the body's muscle protein content every 3–4 months (Wall & van Loon, 2013). This constant renewal of skeletal muscle proteins is possible thanks to a fine regulation of protein metabolism under the influence of exercise and nutritional stimuli. Any type of exercise (endurance or force based) increases catabolic reactions or muscle breakdown due to an increased utilisation of muscular amino acids, accentuated in certain conditions of exercise inducing muscle damage such as downhill running (Doering, Jenkins *et al.*, 2016). At rest, the protein metabolism is also dependent on the fluctuation of anabolic and catabolic reactions mainly regulated through dietary intake. Therefore, it is classically recommended to athletes to ingest a minimal amount of proteins (20 g or 0.3 g/kg body mass) every 3–4 h, time necessary to absorb, digest and stimulate muscle protein synthesis mechanisms to maintain a constantly elevated level of anabolism (Areta *et al.*, 2013; Moore *et al.*, 2009). This recommendation is even more important in the immediate post exercise period to maximise muscle protein synthesis for the next 24 h and optimise muscle recovery (Biolo, Maggi, Williams, Tipton, & Wolfe, 1995; Biolo, Tipton, Klein, & Wolfe, 1997; van Loon, 2013). However, significant reductions in resting and post-exercise muscle protein synthesis rates have been reported with ageing. This anabolic resistance has been observed both in response to muscle contraction (Kumar *et al.*, 2009) and/or amino acid feeding (Burd, Gorissen, & van Loon, 2013; Wall *et al.*, 2015) in ageing populations. Although it is not known at which age the anabolic resistance is triggered and whether it can be delayed with training, older people need greater amounts of dietary proteins compared to their young counterparts to stimulate muscle protein synthesis to similar levels (Symons, Sheffield-Moore, Mamerow, Wolfe, & Paddon-Jones, 2011). As such, current recommendations for protein intake for ageing people are ≥ 30 g per meal (instead of ≥ 20 g per meal for young adults) evenly spaced every 3–4 h to maintain a high anabolic stimulus and thus maintain muscle mass (Paddon-Jones & Leidy, 2014). In a recent literature review, Doering, Reaburn, Phillips, & Jenkins (2016) even suggested a higher amount (35–40 g of proteins per meal or approximatively 0.4 g/kg of body mass) for master endurance athletes participating in muscle damaging exercises such as downhill running. In older moderately active men (mean age: 71 years), practically, these recommendations correspond to a minimum of four portions of ≥ 30 g proteins per day, for breakfast (at 8 am), lunch (12 pm), afternoon snack (4 pm) and dinner (8 pm) for a total of around 120 g of protein or 1.5 g/kg of body mass for an 80 kg athlete.

In order to counteract the reduced muscle recovery capacity observed in master athletes (Easthope *et al.*, 2010; Fell, Reaburn, & Harrison, 2008), a protein rich snack should also be recommended in the immediate post-exercise period (*i.e.* within the first hour), in particular for master athletes participating in eccentric-based activities such as running (Doering, Reaburn, Phillips *et al.*, 2016). It is thus recommended to practitioners and coaches working with master athletes to prepare examples of meals and snacks containing good quality protein sources. The best protein sources to promote muscle protein synthesis are those containing essential amino acids and leucine in particular. Leucine is well-known for its role as precursor of muscle protein synthesis (Layman, 2002). In a 14-day bed rest study with recreationally active people, English *et al.* (2016) showed that leucine supplementation (0.06 g/kg per meal) limited the reduction in muscle protein synthesis (10% decline) compared to a placebo (30% decline). Leucine supplementation also protected knee extensor force production (7% decline) compared to placebo (15% decline). The best sources of leucine are dairy products and whey protein powders (Pennings *et al.*, 2011; Rutherfurd, Fanning, Miller, & Moughan, 2015). Many studies have reported the greater effects of whey protein, which is rapidly absorbed and digested compared to slower proteins such as casein and soy proteins on post-exercise muscle protein synthesis rate in young (Tang, Moore, Kujbida, Tarnopolsky, & Phillips, 2009) and older athletes (Burd *et al.*, 2012; Pennings *et al.*, 2011; Yang *et al.*, 2012). However, it is important to mention that any protein source always constitutes a better choice than carbohydrates or lipid based foods when muscle protein synthesis is sought. For example, Robinson *et al.* (2013) showed that simply increasing the portion size of meat (170 *vs.* 113 g) ingested in the meal after a resistance training session increased muscle protein synthesis by 47% in master athletes (mean age: 59 years). This result was corroborated in a recent meta-analysis showing that master athletes (mean age: 71 years) with a higher protein intake (1.34 g/kg/day *vs.* 1.21 g/kg/day) presented higher muscle strength and quality (Di Girolamo *et al.*, 2017). As such any source of protein (of animal or vegetal origin) under any form (solid, liquid or semi-liquid) should be considered when maintaining muscle mass and/or optimising muscle recovery is a priority. Table 1 presents examples of good quality protein sources that master athletes should prioritise in every meal or snack on a daily basis.

Even though protein intake alone can allow a metabolic milieu that is conducive to muscle protein synthesis, it is important to remind that the optimal strategy to promote muscle protein synthesis must include a combination of intense resistance exercise and protein intake in the closest possible proximity to the training session (Burd *et al.*, 2011; Cermak, Res, de Groot, Saris, & van Loon, 2012; Tieland, Borgonjen-Van den Berg, van Loon, & de Groot, 2012).

Finally in order to maximise muscle protein synthesis and thus maintain muscle mass, it is recommended to master athletes to prolong their protein intake until late at night in the form of evening snacks ingested before bedtime. Indeed several studies conducted with young adults have reported an increase in muscle protein synthesis rate until the next morning (+7 h post ingestion) thanks to the late ingestion of slow release protein (casein) before bed (Groen *et al.*, 2012; Res *et al.*, 2012). This strategy is promising in particular for master athletes increasing their training load, wishing to increase their muscle mass or struggling to maintain their muscle mass.

Table 1. Examples of good quality dietary protein sources to mix and match in the athlete's daily diet to obtain 30–40 g of proteins per meal/snack. Nutritional information calculated with a nutrition analysis software (Nutritics, Dublin, Ireland) using mainly three food databases, the UK composition of foods integrated dataset (CoFID) published by public health England (2019), the United States department of agriculture (USDA) national nutrient database for standard reference, and the Irish foods composition database.

	Amount of proteins (g)
Animal sources	
1 medium chicken/turkey fillet (~120 g)	35
1 medium beef steak (~110 g)	31
1 small tin of tuna in brine (100 g)	25
1 medium fish fillet (~100 g)	22.5
Whey/casein protein powder (30 g)	22.5
3 medium eggs	20
Cow milk (500 ml)	18
Greek style yogurt (200 g)	12
Vegetal sources	
Tofu/soy meat (~100 g)	16
Soy milk (500 ml)	12
Boiled pasta (~200 g)	11
Chick peas (~100 g)	7
Red kidney beans (~100 g)	7
Boiled rice (~200 g)	5
Almonds (~12 g = 12 units)	2.5

4 Periods of metabolic crisis with ageing

It is well reported that the aging process is accompanied by a gradual decrease in muscle mass of around 6–8% per decade after the age of 30 years, especially for sedentary people (Janssen, Heymsfield, Wang, & Ross, 2000; Lexell, 1995). The term sarcopenia is commonly used to characterise the decrease in muscle mass with ageing and subsequent alterations of functional capacities (Baumgartner *et al.*, 1998). The main cause of muscle mass loss with ageing is a gradual reduction in physical activity associated with reduced availability in certain nutrients (Boirie, 2009; Matthews *et al.*, 2008). On the contrary, master athletes continue to train and sometimes are even more active than their young counterparts but are still at risk of muscle mass loss. This is mainly due to periods of forced inactivity associated to malnutrition and reduced anabolic efficiency in response to protein intake due to ageing and immobilisation. These periods of forced inactivity are generally triggered by pathologies, surgeries or hospital treatments. For example, when a master athlete undergoes a hip surgery followed by several days of inactivity at the hospital, this time period is to be considered as critical for muscle metabolism. This situation is critical due to the well-known deleterious effects of immobilisation on muscle mass. Bed rest studies have reported an average decrease of ~0.5% of total muscle mass per day of immobilisation and the effect is even accentuated for lower limbs compared to upper limbs (Wall & van Loon, 2013; Wall *et al.*, 2014). In the event of a succession of injuries or surgeries each involving several days of immobilisation over several years, and without adapted physical and nutritional intervention, muscle mass may inevitably decline towards critical levels (English & Paddon-Jones, 2010; Janssen *et al.*, 2000).

Knowing the deleterious effects of inactivity, these critical moments must be identified and a particular attention must be brought to the nutritional recommendations provided to master athletes who are forced to reduce or even stop their activity for several days. As presented in the previous paragraph, protein intake must be prioritised, with good quality protein sources (mainly containing leucine amino acid) evenly distributed every day (every 3–4 h) and in good proportion (minimum 30 g or at least 0.4 g/kg of body weight per meal or snack) to stimulate muscle protein synthesis. Proteins in the form of gels, drinks and concentrated shots may be recommended if appetite is suppressed and the athlete struggles to ingest solid sources of proteins. Muscle activity must be resumed as early as possible in the form of normal physical activity or at least electrical neuromuscular stimulation if the athlete must remain immobile (Wall *et al.*, 2012). When macronutrient and energy requirements are met, supplements can also be considered in the form of creatine monohydrate (10 g/day for 2 weeks followed by 5 g daily) and beta-hydroxy-beta-methylbutyrate (HMB, 3 g/day) to promote muscle protein synthesis and avoid muscle protein catabolism, respectively, especially during the immobilisation and rehabilitation phase (Hespel *et al.*, 2001; Wilkinson *et al.*, 2013). Recently, the attention has also been brought on the potential of fish oil-derived omega-3 fatty acids to increase post-exercise muscle protein synthesis. A few studies have reported that a fish oil supplementation (2 to 4 g/day for up to 8 weeks) could increase muscle anabolic response to resistance training and adequate protein intake in adults of all ages associated with gains in strength and functional capacity (Rodacki *et al.*, 2012; Smith *et al.*, 2011).

Another important practical consideration for master athletes enduring a period of inactivity is to adapt their energy intake to their energy expenditure, the latter declining due to the reduction of physical activity. Therefore, energy intake should be adapted to the temporary lowered energy requirements for preserving muscle protein synthesis. Practically, carbohydrate intake should be maintained low (< 2.5 g/kg body mass/day) and fat intake maintained around 1–1.5 g/kg/day in order to avoid a calorie surplus and reduce the risk of increase in fat mass (Milsom, Barreira, Burgess, Iqbal, & Morton, 2014). Carbohydrates should be chosen amongst those classified as low-moderate glycemic in nature and restricted to main meals of breakfast, lunch and dinner. Following immobilisation, when the athlete can return to full weight bearing activities such as walking and resistance based exercises,

Table 2. Examples of dietary meal plans for a master athlete enduring a period of immobilisation followed by a rehabilitation/return to training period. Nutritional information was calculated with a nutrition analysis software (Nutritics, Dublin, Ireland) using mainly three food databases, the UK composition of foods integrated dataset (CoFID) published by public health England (2019), the United States department of agriculture (USDA) national nutrient database for standard reference, and the Irish foods composition database.

Meal (Time)	Immobilisation phase	Rehabilitation/training phase
Breakfast (7 am)	3 fried eggs + 1 avocado + 1 slice brown bread + 1 fresh orange	1 medium banana + 200 ml orange juice + porridge (with 100 g oat flakes, 28 g honey, 250 ml semi-skimmed milk, 40 g mixed nuts and raisins)
Morning snack (10 am)	200 g yogurt + 15 blueberries	40 g Whey protein powder with 250 ml water + 1 pear
Lunch (1 pm)	200 g mixed salad with olive oil + 1 medium chicken breast without skin (120 g) + 80 g boiled courgettes + 160 g boiled basmati rice + 250 ml semi-skimmed milk	200 g boiled pasta + 1 tablespoon olive oil + 1 medium chicken breast without skin (120 g) + 80 g boiled courgettes + 140 g fruit salad
Afternoon snack (4 pm)	40 g Whey protein powder + 250 ml semi-skimmed milk	1 medium banana + 150 ml apple juice + 40 g Whey protein with 250 ml water
Dinner (7 pm)	200 g mixed salad with olive oil + 1 tomato + 1 average salmon darn + 160 g protein rich yogurt	200 g mixed salad with olive oil + 200 g boiled basmati rice + 1 average salmon darn + 115 g baguette bread + 150 ml apple juice + 1 Greek style fruit yogurt (125 g)
Evening snack (10 pm, approx. 30–60 min before sleep)	40 g Casein protein powder + 250 ml semi-skimmed milk	40 g Casein protein powder + 250 ml semi-skimmed milk
Approximate daily macronutrient intake	2289 kcal: 148 g CHO, 207 g PRO, 97 g FAT	3268 kcal: 440 g CHO, 200 g PRO, 79 g FAT
Approximate daily macronutrient intake (relative to body weight)	28.3 kcal/kg: 1.8 g/kg CHO, 2.6 g/kg PRO, 1.2 g/kg FAT	40.85 kcal/kg: 5.5 g/kg CHO, 2.5 g/kg PRO, 1 g/kg FAT

CHO, carbohydrate; PRO, protein; FAT, lipid.

dietary feeding should be adapted accordingly. Daily energy intake should be increased specifically by consuming more carbohydrates (4 to 6 g/kg/day) while protein intake should remain high (> 2 g/kg/day with an even distribution over day) and fat intake should remain similar to the immobilisation phase. Table 2 shows an example of dietary meal plans for a 80 kg master athlete who must stay immobile in bed for several days due to surgery followed by the rehabilitation/return to training phase. It is also important to keep in mind that the macronutrient periodisation proposed in this paper is based on interventional case studies with young adult athletes adapted to master athletes' characteristics. Additional studies involving master athletes are required to confirm these recommendations.

5 Summary of nutritional strategies for master athletes

Even though the energy requirements of master athletes are not yet well-known, the current literature on ageing and analysis of main metabolic challenges faced by master athletes constitute a good base to establish nutritional recommendations for this category of athletes.

Firstly master athletes should eat enough food and thus calories to maintain a sufficient energy availability, *i.e.* energy required for daily life activities such as walking, commuting, doing the households, working. Energy availability (EA) can be calculated by using the equation developed by Loucks & Thuma (2003) where EA (kcal/kg LBM/day) = ExEE – EI / LBM, with ExEE corresponding to energy expended during physical exercise, EI corresponding to energy intake (in kcal) and LBM corresponding to lean body mass (in kg). According to the recent literature, EA should be maintained above 30 kcal/kg LBM/day to allow good adaptation to training and stay in good health.

When the calculation of EA is not possible, master athletes should at least make sure they meet the energy requirements of their training sessions. A good knowledge of energy expenditure related to different sporting activities is thus paramount. Athletes can find support by wearing activity monitors and/or heart rate monitors that provide estimation of energy expenditure.

Similarly to their young counterparts, carbohydrate intake must be periodised according to the work required, from low daily amounts (< 2.5 g/kg/day) for resting or easy training days through to high and very high amounts

($>$ 8–10 g/kg/day) for high intensity training or competition days. High carbohydrate availability around (pre, during and post) high intensity training sessions should be prioritised to allow high energy supply and high exercise intensity.

Protein intake must be prioritised at all times. Protein sources must be ingested in every meal and snack (every 3–4 h) in sufficient amount ($\geq$ 30 g) and leucine sources should be preferred whenever possible. Mixing and matching between protein forms is recommended to facilitate the ingestion of adequate amounts. Protein intake must be anticipated and planed during periods of immobilisation.

Fat intake must remain moderate (~1–1.5 g/kg/day) and sources of omega 3 fatty acids should be preferred for their anti-inflammatory properties. Mixed nuts, avocado, fat fish are good examples of omega 3 sources.

Energy supplements are not required if the energy requirements of physical activity and daily life activities are met. Practitioners and master athletes are recommended to adopt a food first approach whenever possible. Protein powders, protein gels or concentrated shots can help maintain the adequate protein intake. Other supplements such as creatine and HMB may bring benefits during specific periods of immobilisation to help promote muscle protein synthesis. Fish oil-derived omega-3 fatty acids may present an interest to stimulate muscle protein synthesis in response to training but additional research is required. Finally micronutrient supplementations including various vitamin and minerals are not necessary unless a deficiency can be confirmed through blood testing. Athletes wishing to take supplements should seek advice from an accredited dietitian/sport nutritionist and should make sure that they consume "informed sport" products which are batch tested for potential contamination with illegal substances.

6 Conclusion and perspectives for future research

Very few data exist on the nutritional requirements of master athletes. Despite exceptional physical capacities, master athletes are still exposed to normal biological ageing which may modify their nutritional needs. Although we have listed a series of nutritional recommendations adapted to master athletes, many questions remain unanswered and warrant a greater effort of research. It can be hypothesised that the energy expenditure and glycogen cost of many activities may increase with ageing, thus modifying nutritional recommendations. As a complement, the spontaneous energy intake of master athletes involved in various sporting disciplines should be investigated in different situations of training and competition to improve our understanding of this specific population and better inform nutritional recommendations. Emerging nutritional manipulations designed to stimulate the adaptation to training such as train low strategies (where carbohydrate intake is voluntarily withhold or reduced at certain periods of training) should also be tested with master athletes to verify their application with ageing.

Author contribution

All authors contributed equally to the paper.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to this article.

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