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Nutrition for master athletes: is there a need for specific recommendations?

Title: Nutrition for master athletes: is there a need for specific recommendations?

Running head: Nutritional considerations for master athletes

Abstract

Master athletes are often considered as exemplars of successful aging thanks to their capacity to maintain a high sports performance during their entire life. A high training capacity, regular participation in sporting competitions and delayed alterations in body composition and physiological capacities have been listed amongst the main factors contributing to impressive master athletes' performances. On the contrary, there is a paucity of data on metabolism and dietary habits of master athletes and the question of whether they need to adapt their nutrition to the aging process remains open. Herein we present a contemporary overview of metabolic challenges associated with aging, including the risk of low energy availability, anabolic resistance and periods of metabolic crisis due to forced immobilization. After assembling scientific evidence to show that master athletes must adapt their dietary intake, we propose a summary of nutritional recommendations for master athletes and suggest the next stage of research.

Keywords: energy intake, protein, muscle mass, diet, aging

Introduction

Progressive deconditioning due to low physical activity is reported to accelerate the aging process through rapid alteration of muscular, cardiorespiratory and metabolic capacities (Wright & Perricelli, 2008). When the decline in intrinsic physical capacities such as muscle force, 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 aging such as sarcopenia, osteoporosis, obesity and cardio-respiratory pathologies (Biolo, Cederholm, & Muscaritoli, 2014). The aging of the population is also generally accompanied by a gradual increase in public heath expenses and warrants the search for new strategies to promote healthy and active aging (Janssen, Shepard, Katzmarzyk, & Roubenoff, 2004; Olshansky et al., 2005).

Certain people such as master athletes consider aging differently. Based on a recent review, master athletes (≥40 years old) can be defined as healthy subjects who train regularly during their entire 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). An increase in the participation of master athletes in various sporting competitions (i.e. endurance events such as long marathon running and triathlon as well as non-endurance athletic competitions such as jumping an throwing events) is also reported along with an improvement of records in all master's age groups (Bernard et al., 2010; Kundert, Nikolaidis, Di Gangi, Rosemann, & Knechtle, 2019; Nikolaidis, Zingg, & Knechtle, 2017; Trappe, 2007). Master athletes are thus often considered genuine exemplars of successful aging (Geard, Reaburn, Rebar, & Dionigi, 2017). The observation of their lifestyle habits (i.e. training, diet, sleep) and their physical capacities also represents a valuable resource to better understand the primary biological aging (i.e. not influenced by environmental factors such as sedentariness) and strategies for healthy aging (Lazarus & Harridge, 2017; Louis, Hausswirth, Easthope, & Brisswalter, 2012; Louis, Vercruyssen, & Bernard, 2018; Sultana et al., 2012).

With this in mind, this article aims to examine the conditions required for healthy and active aging. We focus our attention on nutritional strategies (i.e. by adopting a food first approach) that are considered as key determinants of training adaptation and sporting performance. Given that limited data is available on the impact of nutrition in healthy aging 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 aging on muscle metabolism with an emphasis on nutritional strategies to overcome anabolic resistance. We then identify the key moments in master athletes' life during which nutrition must be optimized. Finally we provide practical nutritional recommendations and suggestions for the next stage of research. To prepare this narrative review, a literature search was conducted on the PubMed, Scopus and SPORTDiscus databases. Search terms included 'master' or 'senior' or 'older' or 'veteran' or 'age' and 'exercise' or 'nutrition' or 'metabolism' or 'diet'. Electronic database searching was supplemented by examining the reference lists of relevant articles. Due to the paucity of data available on nutrition for master athletes, no exclusion criteria were applied for training load and performance level.

Challenge n°1: resisting to reduced energy intake

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; Drewnowski

& Evans, 2001). Physical activity classically leads to an increase in energy expenditure, which must be sustained through an increased 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 following 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. The energy available corresponds to the amount of energy left for daily life activities such as walking, sleeping, eating, commuting to and from work and excluding energy expenditure related to sporting exercise. Energy availability (EA) can be estimated by subtracting energy expended during sporting activities (ExEE, exercise energy expenditure) from energy intake, and normalizing the resulting value to the individual's lean body mass (Loucks & Thuma, 2003). EA below 30 kcal/kg lean body mass/day is considered as low EA and is generally associated with a number of endocrine-metabolic alterations gathered under the term Relative Energy Deficiency in Sport (RED-S). It must be noted that RED-S impairs many physiological functions including, but not limited to, metabolic rate, bone health, immunity, menstrual function, protein synthesis, cardiovascular health and can affect both males and females (Mountjoy et al., 2014). As such, a particular attention should be brought to the maintenance of sufficient energy intake adapted to the requirements of master athletes. The attention must be even greater for master athletes involved in endurance or long distance activities eliciting high levels of energy expenditure.

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 aging might require modification/adaptation of the master athletes' diet. For example, maintaining a balanced diet adapted to the demands of the sport may become a challenge with aging. The main difficulty encountered by master athletes may be a reduction in spontaneous energy intake which can lead to energetic deficit and even deficiencies in essential macro- and micronutrients (i.e. vitamins, minerals). This decrease in energy intake has been reported through dietary surveys conducted mainly with sedentary aging people (Morley, 2000). Wolfe and Miller (2008) reported that one third of adults over 50 years of age failed to meet the recommended daily allowance (RDA) for protein (0.8g/kg/day), yet an important macronutrient to preserve lean body mass. While the risk of inadequate energy intake exists with aging, to date there is no clear evidence of insufficient energy intake in master athletes. The majority of studies investigating the dietary intake of master athletes compared to age-matched sedentary people have reported higher energy intakes for master athletes. Butterworth, Nieman, Perkins, Warren, and 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 and Nichols (2003) reported an average energy intake of 2079 and 2001kcal/day in female master athletes (runners and cyclists) regularly taking or not taking dietary supplements (mainly vitamin and minerals), respectively. It was concluded that the energy intake was greater for the master athletes of this study than the energy intake (1632kcal/day) reported by the US Department of Agriculture for non-athletic women of 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 2.6h per day. The average 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 RDA for young athletes. Recently, using dietary recall, Doering, Reaburn, Cox, and 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 (22.7kJ/kg) than young triathletes (37.8kJ/kg). In master triathletes, post-exercise carbohydrate intake was also less (0.7g/kg) than recommended for optimal recovery (1.0g/kg) and less than their young counterparts (1.1g/kg). Post-exercise protein intake also tended to be lower in masters (19.6g) compared to young triathletes (26.4g). Taken together, studies conducted with recreationally trained aging populations compared to sedentary people of the same age suggest that regular physical activity may lower the risk of nutritional deficit with aging. Thus, we can hypothesize that master athletes might be more sensitive to the important role of nutrition in daily lifestyle than their sedentary counterparts, and would seek to optimize their dietary intake. However, the recent results from Doering, Reaburn, Cox, et al. (2016) including athletic populations show that master athletes are still at risk of inadequate energy intake, which may 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 aging. The gold standard technique of doubly labelled water should be prioritized, 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 can also inform on substrates oxidized during the activity and potential alterations of metabolism with aging.

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 aging. RMR accounts for ~60-75% of total daily energy expenditure and its decline could alter the capacity to regulate the energy balance (Fukagawa, Bandini, & Young, 1990). 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, reduced skeletal muscle protein turnover as well as slowed organ metabolic rate, are the main factors responsible for this gradual decline in RMR with aging (St-Onge & Gallagher, 2010; Wilson & Morley, 2003). Interestingly, regular physical activity and adequate energy intake have the potential to maintain muscle mass and lower the increase in fat mass, thus maintaining RMR with aging. Hayes et al. (2013) reported that chronic exercise (4-5 endurance training session per week) was effective in lowering fat mass and maintaining fat free mass in 20 master athletes (mean age: 60.4 years) compared to 28 age-matched sedentary counterparts (mean age: 62.5 years). In the same study, master athletes also presented a higher salivary testosterone concentration which could participate in the maintenance of muscle mass and subsequently RMR. A significant positive correlation between physical activity associated with adapted energy intake and RMR was also reported for both males (van Pelt, Dinneno, Seals, & Jones, 2001) and females (Van Pelt et al., 1997). In these studies, males (mean age: 63 years) and females (mean age: 58 years) regularly trained mainly in endurance for 7.6h per week, and their average energy intake was 2573kcal/day (with 4.7g/kg/day for carbohydrates, 0.9g/kg/day for fat and 1.2g/kg/day for protein) and 1995kcal/day (with 4.9g/kg/day for carbohydrates, 1.0g/kg/day for fat and 1.3g/kg/day for protein) for males and females respectively. Even though the macronutrient intake was not optimal or not described in these studies, the results suggest that master athletes who are able to maintain a high training volume and sufficient energy intake with age, could maintain their body composition, metabolism and ultimately RMR.

Finally, perceptive factors such as appetite could also influence energy intake of master athletes. A loss of appetite is classically reported with aging and is often termed as “anorexia of aging” (Morley & Silver, 1988). It is estimated that ~25% of home dwellers suffer from anorexia of aging and up to 85% in nursing home populations (Roy, Gaudreau, & Payette, 2016). This phenomenon could be explained by several factors including alteration of the sensitivity of satiety, anorectic and hunger hormones, aging of the gut, diminished smell, taste and salivary secretion but also social and environmental factors (loneliness, difficulties with cooking, eating) (Cox, Ibrahim, Sayer, Robinson, & Roberts, 2019). To the best of the authors’ knowledge, to date no information exists about appetite of master compared to younger athletes. Additional research involving master athletes is warranted to verify whether regular physical activity may help maintain appetite sensations and contribute to the maintenance of energy intake.

Challenge n°2: overcoming anabolic resistance

Skeletal muscles have plastic properties that allow a constant remodeling of their structures through acute and chronic mechanisms of protein synthesis (anabolism) and breakdown (catabolism). The respective contribution of these two mechanisms determines whether muscle tissue grows (hypertrophy) or decreases (amyotrophy) (Burd, Tang, Moore, & Phillips, 2009). For both resistance and endurance athletes, the remodeling of muscle tissue is essential to eliminate protein damaged during exercise and stimulate the resynthesis of new functional proteins. It is reported that muscle protein turns over at a rate of 1-2% per day, equating to 500-600g of muscle that is broken down and resynthesized over 24h, 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 utilization of muscular amino acids, accentuated in certain conditions of exercise inducing muscle damage such as downhill running (Doering, Jenkins, et al., 2016). At rest, 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 (20g or 0.3g.kg body mass) every 3-4h, time necessary to absorb, digest and stimulate muscle protein synthesis mechanisms to maintain an elevated level of anabolism (Areta et al., 2013; Jager et al., 2017; Moore et al., 2009). This recommendation is even more important in the immediate post exercise period to maximize muscle protein synthesis for the next 24h and thus optimize 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 aging. 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 aging 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 aging people are ≥30g per meal (instead of ≥20g per meal for young adults) evenly spaced every 3-4h to maintain a high anabolic stimulus and thus muscle mass (Paddon-Jones & Leidy, 2014). In a recent literature review, Doering, Reaburn, Phillips, and Jenkins (2016) even suggested a higher amount (35-40g of proteins per meal or approximatively 0.4g/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), Yang, Breen, et al. (2012) also showed that 40g of whey protein ingested after a resistance training session increased muscle protein synthesis to a greater extent compared to 20g. In summary, consistently increasing protein intake post-exercise and regularly every 3-4h during the day, facilitates muscle repair and remodeling. Practically, this recommendation corresponds to a minimum of four portions ≥30g proteins per day, for breakfast (at 8am), lunch (12pm), afternoon snack (4pm) and dinner (8pm) for a total of around 120g protein or 1.5g/kg of body mass/day for an 80kg athlete (figure 1).

insert figure 1 here

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 recovery 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 or 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 (0.06g/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, Churchward-Venne, 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. 113g) ingested in the meal following 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: 71years) with a higher protein intake (1.34g/kg/day vs. 1.21g/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 optimizing muscle recovery is a priority. Table 1 presents examples of good quality protein sources that master athletes should prioritize in every meal or snack on a daily basis.

insert table 1 here

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). In a meta-analysis, Cermak et al. (2012) reported that master athletes who consistently consumed dietary protein around the time of resistance training sessions presented a 33 and 38% greater increase in fat-free mass and muscle strength, respectively, compared to those not consuming protein around training time. The results from Burd et al. (2011) also add that exercise should be performed until voluntary fatigue to maximally promote muscle protein synthesis. In the latter study, a leg extension exercise completed either at 90% or 30% of 1 repetition maximum (1RM) until volitional failure immediately followed by the ingestion of 15g whey protein increased myofibrillar protein synthesis (recorded post 24h) in a greater proportion compared to a resting condition with protein feeding only. Interestingly, when the same exercise was completed at 30% 1RM but not until failure (the exercise was work-matched to 90% failure condition) followed by the same protein feeding, the protein synthesis rate was not augmented compared to the resting condition.

Finally in order to maximize muscle protein synthesis and thus maintain muscle mass, master athletes are recommended 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 (+7h 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.

Challenge n°3: navigating through life transitions

It is well reported that the aging process is accompanied with a gradual decrease in skeletal muscle mass of around 6-8% per decade after the age of 30 years, accentuated in sedentary people (Janssen, Heymsfield, Wang, & Ross, 2000; Lexell, 1995). The term sarcopenia is commonly used to characterize the decrease in muscle mass with aging and subsequent alterations of functional capacities (Baumgartner et al., 1998; Rolland et al., 2008). Multiple factors and mechanisms contribute to the gradual loss of muscle mass with aging. Lifestyle behaviors such as physical inactivity, smoking and poor diet with reduced availability in certain nutrients, as well as aged-related changes in hormones and cytokine levels are important factors (Boirie, 2009; Matthews et al., 2008; Rolland et al., 2008). In contrast, 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 combined with inappropriate nutrition and reduced anabolic efficiency in response to protein intake due to aging and immobilization. These periods of forced inactivity are generally triggered by pathologies, surgeries or hospital treatments. These situations are critical due to the well-known deleterious effects of immobilization on muscle mass. Bed rest studies have reported an average decrease of ~0.5% of total muscle mass per day of immobilization and the effect is even accentuated for lower limbs compared to upper limbs (Wall et al., 2014; Wall & van Loon, 2013). In the event of a succession of injuries or surgeries each involving several days of immobilization over several years, and without adapted physical and nutritional intervention, muscle mass may inevitably decline towards critical levels (Janssen et al., 2000). Figure 2 proposes a schematic representation of accelerated sarcopenia due to a succession of episodes of muscle disuse over aging, compared with normal progression of sarcopenia, or improved progression thanks to lifelong physical activity combined with adapted dietary intake.

insert figure 2 here

Knowing the deleterious effects of inactivity, these critical moments must be identified and a particular attention must be brought to nutritional recommendations provided to master athletes who are forced to reduce or even stop their activity for several consecutive days. As presented in the previous paragraph, protein intake must be prioritized, with good quality protein sources (mainly containing leucine amino acid) evenly distributed every day (every 3-4h) and in good proportion (minimum 30g or at least 0.4g/kg of body weight per meal or snack) to maximally 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 may also be considered in the form of creatine monohydrate (10g/day for 2 weeks followed by 5g daily) and beta-hydroxy-beta-methylbutyrate (HMB, 3g/day) to promote muscle protein synthesis and avoid muscle protein catabolism, respectively, especially during the immobilization and rehabilitation phase (Hespel et al., 2001; Wilkinson et al., 2013). Recently, the attention has also been brought to 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 4g/day for up to 8 weeks) could increase muscle anabolic response to resistance training and adequate protein intake in adults of all age 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 the energy intake to their energy expenditure, the latter declining due to the reduced 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 <2.5g/kg body mass/day and fat intake maintained around 1-1.5g/kg/day in order to avoid a calorie surplus and reduce the risk of increase in fat mass. Carbohydrates should be chosen amongst those classified as low-moderate glycemic in nature and restricted to main meals of breakfast, lunch and dinner. Following immobilization, when the athlete can return to full weight bearing activities such as walking and resistance based exercises, 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 (≥2g/kg/day evenly distributed over day) and fat intake should remain similar to the immobilization phase. Table 2 shows an example of dietary meal plans for an

80kg master athlete who must stay immobile in bed due to surgery followed by the rehabilitation/return to training phase.

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Summary of proposed nutritional recommendations for master athletes

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

-First, 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 can be calculated by using the equation developed by Loucks and 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 30kcal/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 periodized according to the work required, from low daily amounts (<2.5g/kg/day) for resting or easy training days through to high and very high amounts (>8-10g/kg/day) for high intensity training or competition days. High carbohydrate availability around (pre, during and post) high intensity training sessions should be prioritized to allow high energy supply and high exercise intensity.

-Protein intake must be prioritized at all times. Protein sources must be ingested in each meal and snack (every 3-4h) in sufficient amount (≥30g) 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 immobilization.

-Fat intake must remain moderate (~1-1.5g/kg/day) and sources of omega 3 fatty acids should be preferred for their anti-inflammatory properties and potential implication in muscle protein synthesis. 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 as far as possible. Protein powders, protein gels or concentrated shots can help maintain the adequate amount of protein intake. Other supplements such as creatine and HMB may bring benefits during specific periods of immobilization 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.

Perspectives for future research

Master athletes can be characterised as exemplars of successful aging. The observation of their lifestyle, nutritional and training habits allows a better understanding of the primary biological aging process, while informing on strategies for healthy aging. 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 is the research group's viewpoint that additional studies are necessary to better understand the energy requirements of various sports in which master athletes compete. It can be hypothesized that the energy expenditure and glycogen cost of many activities may increase with aging, thus modifying nutritional recommendations. As a complement, the spontaneous energy intake of master athletes involved in various sporting disciplines (endurance, team sports and resistance based activities) should be investigated in different situations of training and competition to improve our understanding of this specific population and better inform nutritional recommendations. To do so, the utilization of food diaries (through smartphone applications or paper) and snap and send methods (to estimate portion size) could be implemented in future research studies involving master athletes. Finally, emerging nutritional manipulations designed to stimulate the adaptation to training such as sleep low/train low strategies (where carbohydrate intake is voluntarily withhold or reduced at certain periods of training) should be tested (in laboratory controlled conditions) with master athletes to verify their application with aging.

Conclusion

Very few scientific data exist on the nutritional requirements of master athletes. Consequently, this absence of research prevented a systematic review of the literature to gather the evidence and answer our primary research question. Nevertheless, through a review of the literature related to aging, master athletes and nutrition for athletes, we proposed to identify the metabolic challenges master athletes may face and that require specific nutritional recommendations. Our main findings show that master athletes may face a decreased energy and protein intake, anabolic resistance and periods of metabolic crisis due to forced inactivity. Based on the analysis of these challenges and current nutritional recommendations for young athletes and older non-athletic populations, recommendations can be suggested for master athletes. An emphasis should be brought to the maintenance of sufficient energy availability (>30kcal/kg LBM/day) and the ingestion of a greater amount of good quality proteins (≥30g per meal) in particular post exercise and regularly across the day (every 3-4h). However, more research is required to understand the nutritional habits of master athletes, the energy requirements of their sports, and potential metabolic alterations with aging. As such, future studies should help better inform nutritional recommendations for master athletes.

Authors' contribution

The authors contributed equally to this manuscript.

Financial disclosure statement

All authors have reported no financial or other conflicts of interest that might bias their work.

Ethical Standards

This article complies with the current laws. Research involving human participants and/or animals: this article does not contain any studies with human participants performed by any of the authors.

Informed consent

For this type of study, formal consent is not required.

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Figures

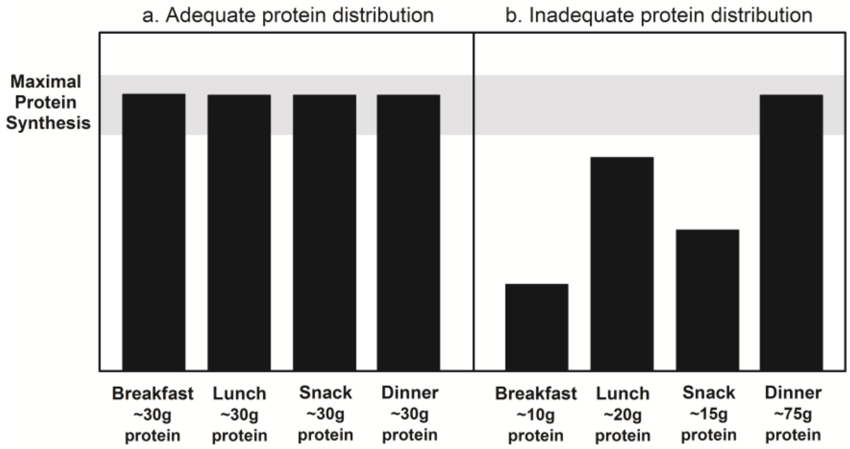

Figure 1: Example of the proposed relationship between the amount of protein ingested per meal and the resultant anabolic response. (a) Ingestion of 120 g of protein, evenly distributed over 4 meals. (b) Ingestion of 120 g of proteins unevenly distributed throughout the day. Strategy “a” is more effective than strategy “b” to stimulate protein anabolic response for the next 24h after ingestion. The grey area represents maximal protein synthesis. Adapted from Paddon-Jones and Rasmussen (2009).

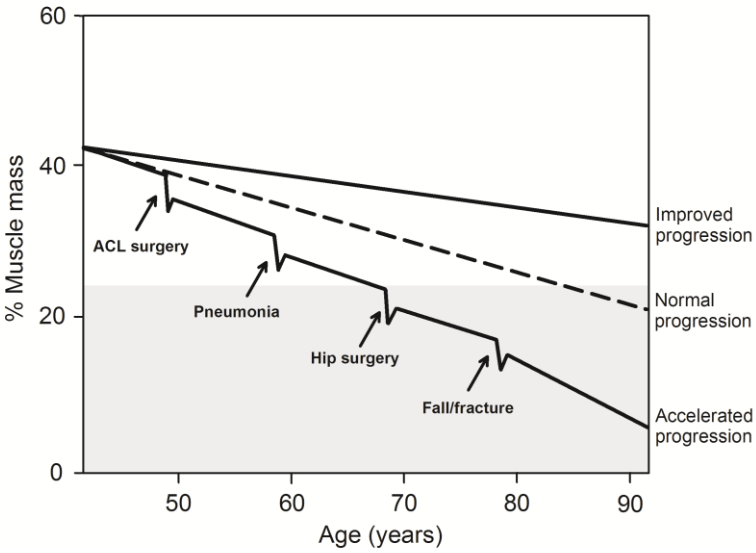

Figure 2: Proposed normal (dashed line), accelerated (irregular line) and improved (solid line) progression model of sarcopenia depending on periods of muscle disuse, physical activity and dietary intake. The frequency and causes of episodes of immobilization (indicated by the arrows) are examples only for the unique purpose of this article. The grey area represents the hypothetical "functional threshold" below which alterations in functional capacities may occur. Adapted from English and Paddon-Jones (2010).

Table 1. Examples of good quality dietary protein sources to mix and match in the athlete's daily diet to obtain 30-40g of proteins per meal/snack. Nutritional information calculated with a nutrition analysis software (Nutritics, Research Edition, 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

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

Table 2: Examples of dietary meal plans for an 80kg master athlete enduring a period of immobilization followed by a rehabilitation/return to training period. Nutritional information calculated with a nutrition analysis software (Nutritics, Research Edition, Dublin, Ireland).

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

CHO, carbohydrate; PRO, protein; FAT, lipid