Nutrition Bulletin

REVIEW

DOI: 10.1111/nbu.12215

Protein intake for athletes and active adults: Current concepts and controversies

B. Egan[*,†]

[*]School of Health and Human Performance, Dublin City University, Dublin, Ireland;
[†]Food for Health Ireland, University College Dublin, Dublin, Ireland

Abstract

The demands of physical exertion mean that protein requirements for athletes and active adults are now accepted as being greater than sedentary populations and those described by population reference intakes of ~0.8 g protein per kg of body mass per day (g/kg/day). Recent scholarly reviews and the latest guidelines for nutrition and athletic performance from the American College of Sports Medicine suggest intakes ranging from 1.2–2.0 g/kg/day whether performing aerobic or resistance exercise, with the higher range of intakes appropriate for the latter. Specific situations of hypoenergetic diet or injury likely require greater protein intakes in order to preserve lean body mass (LBM), which is often paramount in athletes. The optimal dose of protein per meal is 0.25–0.40 g/kg when aiming to maximally stimulate muscle protein synthesis, a marker of repair, growth and adaptation, but multifactorial interactions between protein source, meal timing and pattern of distribution, and macronutrient co-ingestion around exercise influence recommendations on a meal-by-meal basis. Longer term studies are required to confirm the efficacy of these recommendations, which are primarily inferred from data from acute (<24 hours) studies. Notwithstanding the **negative** effects on LBM of higher protein intakes combined with exercise, it would be remiss not to consider potential adverse effects of long-term high-protein intakes, although these concerns are rather preliminary at present. Therefore, within the broad framework of recommended ranges and being cognisant of overall energy and other macronutrient intakes, a personalised and periodised approach to nutrition is required depending on an individual's sport, training volume, phase and goals.

Keywords: amino acids, exercise, muscle, performance, recovery

Introduction

The recently published American College of Sport Medicine (ACSM) *Position Stand on Nutrition and Athletic Performance* (Thomas *et al.* 2016) represents an update on the last 7 years of performance nutrition research and practice. The new guidelines are notable for their evolving perspective towards a more nuanced and personalised approach to performance nutrition, which recognises that requirements are not static and must reflect both the needs of daily training sessions and an individual's body composition [principally fat and lean body mass (LBM)], health and performance goals.

Correspondence: Dr Brendan Egan, Senior Lecturer in Sport and Exercise Physiology, School of Health and Human Performance, Dublin City University, Glasnevin, Dublin 9, Ireland.
E-mail: brendan.egan@dcu.ie

Table 1 Summary of current guidelines on protein intake for athletes

Context	Protein quantity	Quantity for (a) 60 kg, (b) 80 kg, and (c) 100 kg individual	Comments
Daily intake[*]	1.2–2.0 g/kg	(a) 72–120 g (b) 96–160 g (c) 120–200 g	Higher intakes indicated for short periods during intensified training or when reducing energy intake, providing 0.25–0.40 g/kg protein per meal evenly distributed across the day and following strenuous training sessions
Fat loss and calorie restriction[†]	1.8–2.7 g/kg	(a) 108–162 g (b) 144–216 g (c) 180–270 g	Combined with a 500 kcal (~15–20% TDEE) energy deficit and performance of resistance exercise
Post-exercise[‡]	0.4 g/kg	(a) 24 g (b) 32 g (c) 40 g	Combined with 0.8 g/kg CHO to target recovery of muscle glycogen stores in addition to maximal stimulation of MPS
Bedtime[§]	28–40 g	Not yet established	Higher intake supports short-term overnight recovery; lower intake supports hypertrophy goal
Injury[¶]	1.6–2.5 g/kg	(a) 96–150 g (b) 128–200 g (c) 160–250 g	Energy balance should be maintained, but energy intake must reflect reduced TDEE

CHO, carbohydrate; g/kg, grams of protein per kilogram of body mass; MPS, muscle protein synthesis; TDEE, total daily energy expenditure.

[*] Thomas *et al.* (2016).

[†] Murphy *et al.* (2015).

[‡] Beelen *et al.* (2010).

[§] Res *et al.* (2012); Snijders *et al.* (2015).

[¶] Wall *et al.* (2015).

The past decade has seen dynamic research in performance nutrition that is reflected in new recommendations for periodised nutrition around training goals, not least in the area of protein recommendations for athletes and active adults. For instance, while the previous ACSM *Position Stand* (Rodriguez *et al.* 2009), and similarly that of the International Society of Sports Nutrition (ISSN) (Campbell *et al.* 2007), focused on the overall daily intake of protein, particularly as it related to sports on either end of aerobic/endurance or resistance/strength continuum, recent research has highlighted that protein recommendations should be more closely matched to training load and volume, and specific goals of adaptation such as muscle hypertrophy or reduction in body fat. While understandable that the new guidelines do not represent wholesale change, this period of intensive research on protein intakes and nutrient periodisation means that current best practice goes beyond the daily quantity of protein and includes the protein source, dose per meal, distribution throughout the day, timing around exercise, role of macronutrient co-ingestion and maintaining LBM during an energy deficit.

Defining high protein

How much dietary protein is required, optimal, excessive or deleterious? This is a debate that has continued for many years as it relates to athletes, but the current consensus is that the challenge of physical exertion increases the daily requirement for protein *per se* and that specific training loads and adaptive goals, particularly around altering body composition, further influence those requirements (Table 1). The European Food Safety Authority (EFSA) population reference intake (PRI) for dietary protein is currently set at 0.83 g of protein per kg of body mass per day (g/kg/day) (EFSA 2012). This is a minimum recommended intake based around the criterion of nutrition adequacy and on the nitrogen balance method that has been argued to be inappropriate in the context of general population health (Elango *et al.* 2008; Arentson-Lantz *et al.* 2015; Layman *et al.* 2015). Re-analysis of nitrogen balance data and employing the indicator amino acid oxidation (IAAO) method results in recommendations ~40–50% higher than the nitrogen balance method at ~1.2 g/kg protein per day (Elango *et al.* 2008). This equates to recommendations for protein intake in older adults for the maintenance of LBM and function (Deutz *et al.* 2014) and with the lower end of the recommended range for athletes (Thomas *et al.* 2016). However, for athletes and active adults, recommended daily protein intakes go beyond what is minimally required and instead focus on what is optimal or maximises adaptation and recovery to a training stimulus (Phillips & van Loon 2011).

The obvious question is what is 'optimal' with reference to protein intake? In the acute sense, this usually refers to the maximal stimulation of muscle protein synthesis (MPS) as a marker of repair and growth processes, or may refer to the optimal recovery of stores of muscle glycogen through co-ingestion of carbohydrate. Given that growth, repair and adaptation are complementary processes, acute changes in MPS may be viewed as a surrogate measure of these processes during recovery from exercise, be that aerobic or resistance exercise, which can be termed reconditioning (van Loon 2013). In the longer term, this can encompass many facets including maximising muscle hypertrophy in response to resistance training, the maintenance of LBM or immune function during periods of intensified training, or supporting the adaptive remodelling of proteins in muscle, bone, tendon and ligaments to better withstand the stress and strain imposed by future training and performance.

As a consequence, most athletes routinely consume daily protein beyond the recommendations for the general populations. These intakes range from 1.2–2.3 g/kg (male) and 0.8–1.7 g/kg (female) in team sport athletes (Holway & Spriet 2011), whereas intakes up to 3.2 g/kg (male) and 2.5 g/kg (female) are observed in strength and power athletes (Slater & Phillips 2011). Thus, protein intakes of two- to four-fold greater than the PRI on a g/kg/day basis, and representing ~15–30% of daily energy intake, are common amongst athletes. Such intakes are notionally labelled as a 'high-protein diet', although an operational definition of a 'high-protein diet' is still lacking. Daily protein intakes in European populations vary from 12–20% of energy intake (EFSA 2012), so a high-protein diet could be considered to be anything above that range. However, the Institute of Medicine (IOM) has set the Accepted Macronutrient Distribution Range (AMDR) at 10–35% of total energy intake (IOM 2005), so certainly anything above 35% of energy intake should be considered as excessive. According to EFSA, data are insufficient to establish a tolerable upper intake level (UL) for protein, but intakes up to twice the PRI are regularly consumed in Europe and are considered safe (EFSA 2012). For an 80 kg athlete consuming 3200 kcal per day, protein intakes of 1.0, 2.0 and 3.5 g/kg represent 10%, 20% and 35% of energy intake, respectively. Given that the dose of protein which maximally stimulates MPS is ~0.4 g/kg (Morton *et al.* 2015), a meal plan incorporating five meals in this range only requires 2.0 g/kg to satisfy this recommendation, in addition to being cognisant of overall macronutrient and energy intake.

Current concepts informing protein requirements for athletes and active adults

Measurement and interpretation of muscle protein synthesis

The most widely accepted explanation for the control of skeletal muscle mass is that temporal fluctuations in MPS and muscle protein breakdown (MPB) in response to nutrient intake, exercise and inactivity, ultimately dictate the net gain or loss of human muscle protein (Rennie *et al.* 2004). Although MPB has proven technically challenging to measure, the general assumption is that it is change in MPS in response to meals and exercise that is the primary determinant of whether an intervention results in a long-term change in LBM (*i.e.* that MPS exceeds MPB over time).

However, the measurement of MPS, or the fractional synthetic rate (FSR), has until relatively recently been achieved by the infusion of stable isotope-labelled tracers of amino acids and quantification of the rate at which these labelled amino acids are incorporated into tissue (McGlory & Phillips 2014). This method has several limitations, not least that MPS measurements are usually restricted to a 3- to 12-hour period. From these data, inferences are then made about how a given exercise and/or nutrition intervention, if consistently applied over weeks and months, will impact muscle mass, typically measured as LBM or fat-free mass (FFM) using dual X-ray absorptiometry (DXA), or thigh volume by magnetic resonance imaging (MRI). However, these short-term responses in MPS do not always correlate with longer term outcomes for LBM (Mitchell *et al.* 2014), so there must be some caution applied when making recommendations based solely on acute effects on MPS (Atherton *et al.* 2015; Mitchell *et al.* 2015), even though it is quite common to do so.

Recently, a new technique for measurement of MPS over extended periods of time using deuterated water (D_2O, or 'heavy water') stable isotopic tracer methodology has been established (Wilkinson *et al.* 2014). This method requires ingestion of a bolus of D_2O and negates the requirement for intravenous administration of tracers, thereby permitting assessment of MPS in a free-living setting. However, this method is not without its own drawbacks inasmuch as a free-living setting by its nature means that factors such as training volume, particularly if unsupervised, or habitual diet, if not controlled, may influence outcomes of a given intervention (McGlory & Phillips 2014). Therefore, stable isotope infusion and D_2O both undoubtedly have their merits to identify potential anabolic strategies, but their limitations should be considered when translating into practice as described herein.

Protein source

Protein-rich foods include the flesh of ruminants, poultry, game and fish, as well as eggs and dairy; other major dietary sources of protein include legumes, nuts and seeds. Essential amino acids (EAAs) provide the anabolic stimulus, with leucine, in particular, the key AA resulting in the activation of signalling cascades in muscle to increase MPS, predominantly via the mTOR-p70S6K pathway (Atherton *et al.* 2010b; Churchward-Venne *et al.* 2014). To date, the majority of studies that have assessed MPS after exercise and/or nutrition intervention have focused on powdered protein sources such as whey, casein, soya, egg and rice. Most plant-based sources have a leucine content of ~6–8%, whereas animal-based protein sources tend to have a leucine content in the range of ~8–9%, but >10% in the case of dairy proteins (van Vliet *et al.* 2015). Sources of dietary protein with divergent leucine content, and digestion and absorption kinetics exhibit different abilities to stimulate MPS (Tang *et al.* 2009; Burd *et al.* 2015). This has led to the concepts of the leucine 'trigger' and 'threshold' for explaining the stimulation of MPS by protein (Tang *et al.* 2009), whereby leucine acts as the trigger for MPS, but the quantity ingested must exceed a threshold of ~3 g per dose (Morton *et al.* 2015; van Vliet *et al.* 2015).

Because plant-based sources of protein are generally lower in leucine content, animal-based sources have traditionally been considered as higher quality and more effective at stimulating MPS on a per gram basis (van Vliet *et al.* 2015), and the more rapid or pronounced that hyperaminoacidemia occurs after ingestion, the greater the MPS response measured in short time periods (1–6 hours) (Morton *et al.* 2015). However, this may be negated if the quantity of leucine in the protein ingested exceeds the ~3 g threshold (van Vliet *et al.* 2015), because when suboptimal doses of dietary protein are enriched with leucine, a previously submaximal MPS response is consequently maximised (Churchward-Venne *et al.* 2014). In practice, mixed meals rather than protein powders comprise the majority of protein **intaek** on a daily basis. Because the composition of a meal markedly alters the plasma AA profile (Burke *et al.* 2012b), it remains to be con-firmed if the ingestion of mixed meals recapitulates the MPS response to these powder-based feedings. Indeed, the composition of a mixed meal by providing co-ingestion of other macronutrients and micronutrients is a more complete nutrition approach to recovery, but when athletes find it inconvenient to consume such meals, protein supplements offer a practical alternative once due diligence has been performed on their quality and contents.

Dose of protein per meal

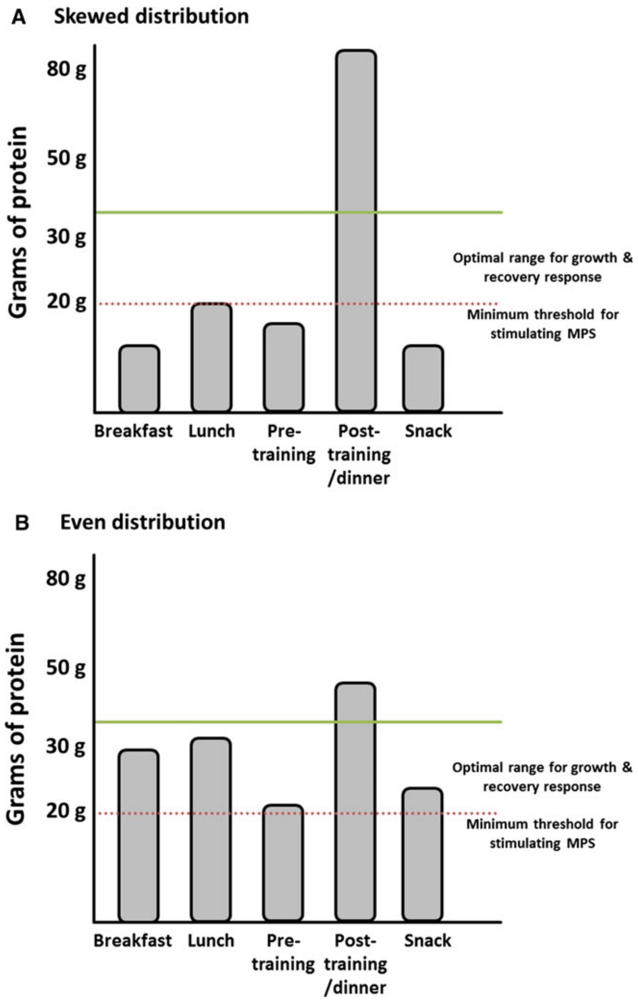
Despite a plethora of studies examining the MPS response to various protein sources and recovery patterns, few have examined the protein dose–response for stimulating MPS in young adults. Two studies exploring the post-exercise stimulation of MPS after protein ingestion have established that 20 g of either egg (Moore *et al.* 2009a) or whey (Witard *et al.* 2014) protein effectively (~90%) maximises MPS. In these studies, this equated to ~0.25 g/kg per dose, and in the latter study, this pattern was also evident at rest. Accounting for the focus on lower body resistance exercise, the potential for inter-individual variation and modelling of data from several laboratories, an intake of 0.40 g/kg per meal has been recommended when aiming to maximise MPS, at least when consuming isolated proteins (Moore *et al.* 2015; Morton *et al.* 2015). That said, for whole food, 30 g protein in the form of 90% lean beef was as effective as 90 g protein at stimulating MPS (Symons *et al.* 2009). Sex-dependent differences have not been investigated on a g/kg basis, but bolus of 25 g given to both males and females did not reveal differences in MPS between the groups (West *et al.* 2012). Therefore, although the extremes of spectrum of athletes from the 50 kg female gymnast to the 120 kg male rugby forward must be inferred, a practical approach in athletes and active adults is to target 20–40 g of protein per meal.

Protein distribution and timing

The role of meal frequency in protein intake is often debated and is best determined by relative goals for health and performance (La Bounty *et al.* 2011; Mattson *et al.* 2014). In pragmatic terms, taking a recommended dose per meal of 0.25–0.40 g/kg, and aiming for targets in the range of 1.2–2.0 g/kg per day, implies that four to six eating occasions separated by 2–4 hours will be a typical approach for athletes and active adults. Supporting this approach is the concept of the 'muscle full effect', a phenomenon when high plasma leucine concentrations are sustained over several hours, muscle exhibits a refractory response with MPS returning to basal levels despite AA availability

(Atherton *et al.* 2010a). In addition, stimulation of MPS exhibits an upper limit in response to a given dose of leucine and associated threshold of plasma concentration (Moore *et al.* 2009a; Glynn *et al.* 2010; Rowlands *et al.* 2015). In contrast, strategic dosing and distribution of AAs with intermittent and pulse feeding can overcome this refractory response via either cyclical oscillation or sustained low amplitude aminoacidaemia and leucinemia to prevent a refractory response (Areta *et al.* 2013). In the acute setting over a 12-hour period, the highest MPS response is achieved when the pattern of whey protein ingestion is 4 × 20 g every 3 hours, when compared to ingestion of large doses (2 × 40 g every 6 hours) or pulsed feeding (8 × 10 g every 1.5 hours) (Areta *et al.* 2013).

The ingestion pattern of 4 × 20 g every 3 hours reflects an 'even' distribution of protein intake, as opposed to the 'skewed' distribution that is typical of the general population (Arentson-Lantz *et al.* 2015), whereby small to modest amounts of protein are eaten at breakfast and lunch, and large intakes are seen at later meal(s) of the day (Fig. 1). Potential merit for an even distribution of protein for higher rates of MPS over a 24-hour period is established. For instance, the consumption of ~30 g of protein at breakfast, lunch and dinner stimulated 24-hour MPS to a greater extent than a skewed isonitrogenous protein intake of 10 g at breakfast, 15 g at lunch and 65 g dinner (Mamerow *et al.* 2014). These studies (Areta *et al.* 2013; Mamerow *et al.* 2014) demonstrate, in principle, that feeding strategies can be optimised to target stimulation of MPS, but are limited to 12- to 24-hour periods and remain to be confirmed as efficacious when repeated over time in free-living settings. For example, no additional increase in LBM was observed when eating occasions providing >20 g of protein were increased from four to six per day during a rugby pre-season (MacKenzie-Shalders *et al.* 2016). However, these athletes were already consuming protein at ~2.6 g/kg and four eating occasions >20 g protein, which may already be optimal, so this may have masked the relative change to protein distribution. Indeed, the suboptimal skewed protein distribution evident in the general population (Arentson-Lantz *et al.* 2015) remains to be confirmed in athletes and active adults.



Figures 1 Conceptual representation of the proposed relationship between protein quantity and distribution pattern and the stimulation of muscle protein synthesis (MPS) over the course of a day. Unbalanced or skewed distribution of protein intake (A); balanced or even distribution of a similar total amount of daily protein (B) (~140 g). An even distribution (B) is proposed to provide a greater aggregate response of MPS for the same amount of total protein and is hypothesised to therefore promote greater muscle hypertrophy in the presence of a training stimulus.

Pre-sleep night-time protein ingestion is another eating occasion that can be targeted in active adults. The ingestion of ~40 g of casein protein prior to sleep increases overnight rates of MPS (Res *et al.* 2012), and daily ingestion of ~28 g of casein protein before sleep during 12 weeks of resistance training resulted in greater improvements in strength and size (thigh cross-sectional area) compared to non-caloric placebo ingestion (Snijders *et al.* 2015). However, similar to the protein distribution scenario, because daily protein intake in the placebo group was only ~1.3 g/kg compared to ~1.9 g/kg in the casein group, it remains to be confirmed whether pre-sleep protein ingestion is necessary or effective in athletes already meeting a protein intake target for muscle hypertrophy (*e.g.* 2.0 g/kg). Alternatively, pre-sleep ingestion may be a practical strategy to increase daily protein intake in those struggling to meet high-protein targets (Table 1).

Interestingly, while the MPS response by definition reflects *muscle* and *synthesis*, it has been argued that if considering a whole-body response and both synthesis and breakdown effects as the overall anabolic effect, then there is unlikely to be an upper limit to the quantity of protein that will provide an anabolic stimulus (Deutz & Wolfe 2013). However, in the light of these data on distribution and timing, maximising MPS over the day through frequent stimulation with meals providing protein at 0.25–0.40 g/kg is a practical approach.

Protein timing around exercise training and the role of macronutrient co-ingestion

A single bout of exercise, both aerobic and resistance, increases rates of both MPS and, to a lesser extent, MPB. However, protein balance after exercise will remain negative in the absence of food intake. Dietary protein ingestion during or immediately after exercise stimulates MPS, inhibits MPB and, as such, stimulates net muscle protein accretion following exercise (Morton *et al.* 2015). The concept of 'nutrient timing' posits that the manipulation of nutrient intakes before, during and after exercise dramatically influences recovery from that session, and the nature of adaptation to training, with effects mediated by nutrient-specific effects on MPS, lipogenesis and glycogen resynthesis (Kerksick *et al.* 2008).

Few studies have examined pre-ingestion of protein for effects on MPS, but despite an early suggestion that pre-exercise ingestion of EAAs increased post-exercise MPS (Tipton *et al.* 2001), several studies since with either EAAs or protein have failed to observe this effect (Tipton *et al.* 2007; Fujita *et al.* 2009; Burke *et al.* 2012a). Although many studies examining the MPS response to exercise and nutrient intake have been performed on fasted participants, in practice most athletes will have had a meal within a couple of hours prior to a training session, so much of the focus tends to be on nutrient intakes during and after training. For instance, protein ingestion during exercise increases MPS during both aerobic and resistance exercise (Beelen *et al.* 2008, 2011). A note of caution, although one that remains to be confirmed, is that the aminoacidemia consequent to protein ingestion prior to or during exercise may blunt the subsequent post-exercise MPS response to AAs due to an overlap in the aminoacidaemic responses and the aforementioned muscle full effect. Numerous studies have demonstrated an enhanced MPS response during recovery when a protein source is ingested immediately after exercise, whether comparing to placebo (Tipton *et al.* 2004, 2009) or on a dose–response basis (Moore *et al.* 2009a; Witard *et al.* 2014). Notably, aside from these acute MPS responses, longitudinal studies of nutrient ingestion before and after resistance exercise have demonstrated that this approach enhances gains in LBM compared to the same nutrients ingested in the morning and evening away from training sessions (Cribb & Hayes 2006; Burk *et al.* 2009).

While it is difficult in practice to distinguish recovery from adaptation, hence the term reconditioning (van Loon 2013), recovery generally encompasses activation of restorative processes including recovery of fuel stores (muscle glycogen), repair of damaged muscle, and restoration of fluid and electrolyte balance (Beelen *et al.* 2010). Adaptation generally encompasses changes in muscle structure, function and metabolism consequent to alterations in gene transcription and protein translation induced by exercise training (Egan & Zierath 2013). At the level of MPS, this encompasses changes in myofibrillar, sarcoplasmic and mitochondrial protein fractions, each of which are influenced by the provision of nutrients (Wilkinson *et al.* 2008; Moore *et al.* 2009b; Burd *et al.* 2012). Effects on the recovery of muscle glycogen and MPS go beyond the effects of protein alone, and although the role of fat in the post-exercise reconditioning is not established, the effects of carbohydrate-protein co-ingestion are well established. Compared to ~20–25 g of protein alone, co-ingestion with ~50–100 g carbohydrate during recovery does not augment rates of MPS (Koopman *et al.* 2007; Staples *et al.* 2011; Glynn *et al.* 2013), but the addition of protein (~0.4 g/kg) to a carbohydrate (~0.8 g/kg) bolus does enhance the rate of muscle glycogen resynthesis, especially when carbohydrate intakes are suboptimal (<~1.2 g/kg/hour) (McLellan *et al.* 2014).

Intriguingly, while recovery of muscle glycogen is paramount in preparation for performance in most high-intensity sports, recent evidence supports a 'train low, compete high' approach whereby athletes may train with reduced muscle glycogen stores in order to elicit greater aerobic training and performance adaptations (Burke 2010; Bartlett *et al.* 2015). The mechanistic basis for this approach is beyond the present scope but in short-term training interventions, improvements in time-trial performance (Cochran *et al.* 2015) and reduced body fat (Marquet *et al.* 2016) have been recently observed by restriction of carbohydrate intake either between twice daily training sessions or during overnight recovery (so-called 'sleep low'). In these approaches, additional protein becomes a key strategy to maintain energy intake and support the other aforementioned recovery processes, again underscoring the importance of this macronutrient in the athlete's diet. Lastly, the co-ingestion of alcohol is established as deleterious to exercise-induced MPS in the presence of protein ingestion (Parr *et al.* 2014) and attenuates the recovery of muscle function (Barnes *et al.* 2010) and muscle glycogen if displacing carbohydrate intake during short-term recovery (Burke *et al.* 2003). Thus, alcohol intake should be discouraged in the early post-exercise recovery period when aiming to maximise recovery or training adaptations.

Protein intake to maintain lean body mass on a hypoenergetic intake

A higher daily protein intake over time augments resistance exercise-induced increases in LBM, but the magnitude of gains that are attributable to increasing protein intake compared to the overall gains made as a result of a resistance training programme itself is relatively small (Cermak *et al.* 2012), and is a function of how much the nutrition intervention deviates from habitual protein intake (Bosse & Dixon 2012). On the other hand, weight loss is a common goal amongst athletes and can be achieved by restricting energy (hypoenergetic) intake, increasing training volume or a combination of both. Rather than weight loss, most athletes would prefer fat loss such that the alteration to body mass results in a higher LBM-to-fat-mass ratio, which typically translates into a competitive advantage (Murphy *et al.* 2015). Whereas much of the work cited above relates to the acute stimulation of MPS and inferences made about adaptation that would take place if repeated over time, such an approach is not appropriate for those athletes seeking a reduction in body fat while maintaining LBM wherein longer term studies with objective measures of body composition are required. Few studies have directly examined athletes but, in general, an evidence base exists for higher protein intakes enhancing the retention of LBM during hypoenergetic periods (Krieger *et al.* 2006; Wycherley *et al.* 2012; Helms *et al.* 2014). When combined with exercise, a daily protein intake of 2.3 g/kg/day with 15% energy deficit maintained LBM compared to 1.0 g/kg/day (Mettler *et al.* 2010). Moreover, compared to 1.2 g/kg daily protein intake, 2.4 g/kg/day in the presence of a 40% energy deficit, but combined with a very high volume (6 day/week) of resistance and high-intensity interval training, resulted in an *increase* in LBM and greater loss of fat mass over 4 weeks (Longland *et al.* 2016). This work demonstrated the potent effects of an optimised nutrition and exercise intervention to alter body composition and counters the axiom that muscle cannot be gained in a calorie deficit. The findings remain to be extended to already relatively lean athletes. Importantly, performance parameters are influenced by the rate of weight loss such that rapid weight loss can be deleterious (Garthe *et al.* 2011). Moreover, if the reduced energy intake is achieved by reducing carbohydrate intake, some elements of high-intensity performance may be impaired but conversely 'train low' benefits may be observed. Thus, these considerations again speak to the importance of personalised and periodised approaches in performance nutrition.

Controversies surrounding high protein intakes

Concerns about high-protein diets have historically centred on unnecessary metabolic strain on the kidneys leading to impaired renal function and increased excretion of calcium, thereby increasing the risk for osteoporosis. Both of these concerns have been discussed in detail elsewhere (Bilsborough & Mann 2006; Campbell *et al.* 2007; Westerterp-Plantenga *et al.* 2009; Tipton 2011; Layman *et al.* 2015; Phillips *et al.* 2016), with the consensus being that there is no substantive evidence that protein intakes described herein (Table 1) will have adverse effects in healthy athletes and active adults. In the absence of UL for daily protein intake, assessment of the likelihood of exceeding the UL for individual AAs (*e.g.* leucine, tryptophan, methionine) suggests that this too is unlikely without excessive supplementation (Layman *et al.* 2015).

Recent studies have examined increasing daily protein intakes to as high as 3.4 and 4.4 g/kg/day (~40–45% energy intake) without any adverse effects on health or body composition (Antonio *et al.* 2014, 2015). However, these studies were only 8 weeks in duration and involved individuals already consuming relatively high protein intakes (~1.8–2.3 g/kg/day). Moreover, many interventions of exercise training and increased protein intake to increase LBM last for 12 weeks or less (Cermak *et al.* 2012), so a knowledge gap exists for the effects of longer term high-protein intakes and exercise interventions. Therefore, although current paradigms based around the maximal stimulation of MPS at regular intervals throughout the day imply a high protein intake to maximise muscle reconditioning, the long-term (*i.e.* years) consequences remain to be explored. Conversely, protein intake in ancestral *Homo sapiens* was almost certainly higher than the current pattern of 12–20% of energy intake, being usually >30% of energy intake (Eaton 2006).

Recent publicity against high protein intakes has come as a result of epidemiological studies that have suggested that consuming >20% of energy intake from protein, and animal protein in particular, increases the risk for adverse health outcomes such as cancer and type 2 diabetes (Levine *et al.* 2014; van Nielen *et al.* 2014). In the case of cancer risk, a mechanistic link between improved longevity and reduced cancer risk consequent to the restriction of protein and AAs, especially methionine, which is higher in animal proteins, is well established in lower organisms (Mirzaei *et al.* 2014). Thus, progressing this research beyond existing preliminary human interventions, but particularly isolating the beneficial effects of calorie restriction and/or fasting from the concomitant reduction in protein and AAs, and recognising the relative contribution of other macronutrients, is necessary (Simpson *et al.* 2015).

While valuable, these epidemiological studies (Levine *et al.* 2014; van Nielen *et al.* 2014) cannot establish causation and should not be immediately interpreted to mean that a higher protein intake has clear negative health outcomes. Major confounders such as the quantity of physical activity, the quality of the protein intake (*e.g.* processed versus unprocessed meats) and the method of dietary assessment are underexplored. In contrast, in the presence of physical activity and exercise training, a theme of moderate-to-high protein intake of high-quality protein is desirable, while situations with protein intake are recommended to exceed 2 g/kg/day relate to short-term strategies around injury and altering body composition (Table 1). The inclusion of high-quality animal proteins or combinations of plant proteins can increase overall diet quality and the intakes of nutrients such as calcium, vitamin D, potassium, dietary fibre, iron and folate (Phillips *et al.* 2015). As with any dietary advice, the efficacy is in the translation of scientific concepts and g/kg recommendations into appropriate food choices.

Lastly, it would be remiss not to mention that few, if any, studies have followed up these short-term interventions of exercise training and increased protein intake to consider what happens to LBM trajectories over time, beyond the intervention period, in the presence or absence of the training stimulus and increased protein intake. In other words, clearly LBM is not maintained in the absence of an appropriate training stimulus, but what happens to LBM over time as the body adapts to the increased protein intake provided by an intervention? The relative change in protein intake is crucial (Bosse & Dixon 2012) because the efficiency of protein utilisation adapts to changes in physical activity level, energy balance and amount of protein intake, and these changes occur over time (Millward 2001, 2003). This means that a consistently high protein intake alone does not necessarily lead to maintenance of LBM, whereas sudden as opposed to gradual reductions in protein intake may result in a net loss of LBM.

Table 2 Nutrition strategies relevant to protein intake in athletes and active adults

- Based on the individual's sport/activity, phase of season, specific training volume and goals, establish daily targets for energy intake and the respective macronutrients
- Base macronutrient targets, including protein intake, on a gram per kilogram body mass basis, not on percentage of calories
- Distribute the protein evenly throughout the day, likely in three to four main meals plus one to three snacks, but this will be personalised
- 20–40 g of protein per meal or snack is a general target range
- Be cognisant that training time(s) and protein recommendations around training sessions must be accommodated
- Aside from the traditional breakfast, lunch and dinner, other eating occasions could include but are not limited to a post-exercise meal and may include a pre-sleep night-time protein meal
- Develop a meal plan based on whole foods that will meet established macronutrient targets and distribution
- Emphasise high-quality protein, particularly those sources with higher leucine content, but these should not be limited to animal proteins
- Carbohydrate co-ingestion in the post-exercise period is important when recovery of muscle glycogen is a priority
- For individuals struggling to hit targets with whole foods or who consume lower quantities of leucine-rich foods, consider supplementing conservatively with protein powders or branched chain amino acids

Concluding remarks

The demands of physical exertion mean that protein requirements for athletes and active adults are now accepted as being greater than those described by population reference intakes. The latest guidelines for nutrition and athletic performance intakes ranging from 1.2–2.0 g/kg/day, whether performing aerobic or resistance exercise, and greater intakes in situations of hypoenergetic diet or injury in order to preserve LBM (Table 1). Taking a whole diet perspective informed by a meal-by-meal approach and the multifactorial interactions between protein source, meal timing and pattern of distribution, and macronutrient co-ingestion around exercise, practical nutrition strategies can be implemented on that basis (Table 2). These are in contrast to non-specific, default recommendations of a large, whole diet increase in protein intake. Longer term studies are required to confirm the efficacy of these recommendations and strategies, which are primarily inferred from data from acute (<24 hour) studies, which have been fertile for hypothesis generation but require rigorous investigation in free-living settings. Therefore, within the broad framework of recommended ranges and being cognisant of other macronutrient intakes, a personalised and periodised approach to nutrition is required depending on an individual's sport, training volume, phase and goals.

Conflict of interest

The author's research is funded by Food for Health Ireland, Anabio Technologies (Ireland) and Smartfish AS (Norway). He has previously received honoraria from the National Dairy Council (Ireland). However, the views expressed in this article are those of the author alone.

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