How much protein should you eat?

A comprehensive review of meta-analyses

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Abstract

The recommended daily allowance for protein is 0.8 grams per kilogram of bodyweight per day, or around 50 g per day for the average person. Eating more than the RDA is beneficial for controlling hunger, building muscle mass, and gaining strength—all of which benefit health and healthspan. Yet there is some scepticism towards the notion that "more is better", with some advocating that excessively high protein intakes, beyond 1.6 g/kg/d for example, yield no further benefit or may be actively harmful. This review synthesises the benefits and risks of a high protein diet. The wealth of observational data in humans comes out in favour of "more is better" except for those with pre-existing chronic kidney disease. To determine the optimal protein intake for maximising accretion of muscle mass—which is predictive of healthspan—seven relevant meta-analyses of randomised controlled trials (RCTs) are dissected in detail. Higher daily protein intakes are beneficial for lean body mass at all ranges of intake. With concomitant resistance training, this dose-response relationship is remarkably linear. Therefore, personalised protein intake recommendations in healthy resistance-training individuals should maximise protein intake within financial and practical constraints, but unconstrained by perceptions of health concerns or diminishing returns.

Introduction

Protein is the only nitrogen-containing macronutrient, and is essential for human survival. Globally, over 180,000 people die per year from protein deficiency—with the vast majority being infants and the elderly (fortunately, this figure is now almost four times smaller than what it was in 1980) [1].

The US Institute of Medicine, based on a 2003 meta-analysis of nitrogen balance studies [2], recommends adults consume 0.8 grams of protein per kilogram of bodyweight per day, or 50 g for the average person eating a 2000 kcal diet. However, this number represents the minimum intake to stave off protein deficiency and muscle wasting, not the optimal amount for human flourishing. The Acceptable Macronutrient Distribution Range (AMDR), on the other hand, offers a recommended range of protein intake as part of an optimal diet [3]. This range is 10-35% of calories, which translates to between 0.8 and 2.8 g/kg/d of protein—the upper limit of which is substantially higher than the Recommended Dietary Allowance (RDA).

Within this large range, it is likely that precise optima vary across different populations. To offer more precise guidance for the elderly, an international panel of experts was brought together by the European Union Geriatric Medicine Society in 2013. The resulting PROT-AGE study group reached the conclusion that, for optimal health, adults over 65 years old should consume 1.0-1.2 g/kg/d of protein as a minimum if they are sedentary [4]. However, they also recommended that such adults not be sedentary—prescribing endurance- and resistance-based exercise at an individually tolerable level—and that the inclusion of such exercise increases the protein recommendation above 1.2 g/kg/d. They also noted that most older adults with acute or chronic diseases, with the exception of untreated severe kidney disease, need an even higher protein intake to optimize health, of around 1.2-1.5 g/kg/d.

Despite this, the notion that increasing protein intake above the 0.8 g/kg/d IoM RDA might be beneficial is still rebuked by academics and journalists alike. In a 2019 perspective, Mittendorfer and colleagues concluded that consuming more than 0.8 g/kg/d is not beneficial for muscle mass outside of weight loss and is not beneficial for overall physical function [5]. More recently, the *New York Times* argued the same, insisting that 0.8 g/kg/d is "adequate for most people's basic needs".

Beyond basic needs, the International Society of Sports Nutrition recommends healthy and exercising individuals consume 1.4-2.0 g/kg/d of protein, with resistance trained individuals requiring intakes at the upper end of this spectrum [6]. A combination of endurance and resistance exercise are already uncontroversially recommended for optimal human health, the benefits of which include increased quality of life and reduced all-cause mortality [7,8]. Therefore, the optimal protein intake must assume endurance and resistance training as a given if we are truly optimizing human health.

Yet even among exercising populations, optimal protein recommendations are disputed. For example, science communicators and journalists have recently argued against protein intakes beyond 1.6 g/kg/d, claiming no benefit beyond this intake and even suggesting that such high intakes may be actively harmful [9,10]. This review will summarise and critique the mechanistic data that have led to such assertions of harm, and look at the broader observational signals in human populations.

Beyond observational data, this review will focus not on preventing deficiencies or recommendations for sedentary individuals, but on the optimal daily protein intake for individuals following other healthspan-optimising recommendations. To this end, meta-analyses of randomised control trials (RCTs) focused on the impact of higher protein intake in combination with exercise will be discussed. Inclusion criteria of large meta-analyses, subgroup analyses, and meta-regression adjustments for covariates will be carefully dissected. For example, RCTs with resistance training versus without resistance training; RCTs in younger versus older populations; RCTs in obese versus healthy individuals; and RCTs of untrained versus trained individuals will be differentiated. The resulting synthesis will converge on a recommended daily protein intake for healthy exercising individuals looking to optimise healthspan.

The importance of muscle mass and strength for healthspan

The primary benefit of a higher protein intake is enhanced accretion of muscle mass and increased strength. While historically a niche outcome to optimise for, enhanced muscle strength and size are increasingly at the forefront of efforts to improve human health and healthspan. For example, muscle mass strongly predicts longevity in older adults, with top quartile for muscle mass having 20% lower risk of all-cause mortality than bottom quartile [11]. Further, a 2020 meta-analysis of observational studies found that sarcopenia—defined as the progressive loss of muscle mass and function—was correlated with a wide range of negative health outcomes, from cognitive impairment and depression to metabolic diseases, hospitalization, and all-cause mortality [12].

In addition to muscle mass, muscle strength as measured by grip strength is also significantly negatively correlated with all-cause mortality risk and cause-specific mortality risk from cancer, cardiovascular disease, and respiratory disease according to a UK Biobank prospective cohort study of over half a million participants [13]. Recent Mendelian randomisation studies have also linked grip strength with adiposity and shown that higher grip strength is causally upstream of increased cardiorespiratory fitness [14,15].

Given the strong correlational and causative evidence that resistance training enhances quality of life and reduces mortality risk [16,17], the potential for optimised protein intake to maximise resistance training-induced benefits on muscle mass and strength, and thereby health and healthspan, is of great importance for public health. Meta-analyses of RCTs specifically focused on this question will be discussed later.

Risks of high protein intake

Arguments against excessive protein intake also deserve consideration. Mechanistically, *in vitro* and mouse studies suggest that excessive protein intake may drive atherosclerosis by activating mammalian/mechanistic target of rapamycin (mTOR) in macrophages [18,19]. Of course, mTOR activation is also the mechanism by which protein and resistance training drives muscle protein synthesis, which we know to be beneficial [20,21].

In humans, the story is more complex. Mittendorfer and colleagues have argued that a high protein diet without concomitant carbohydrate restriction may present a risk for metabolic disease [5,22]. This is based on the fact that protein ingestion elevates blood insulin and glucagon levels, which, when chronically elevated, are risk factors for type 2 diabetes. However, this assertion ignores the fact that protein-induced elevations in insulin and glucagon are acute and simultaneous, and so do not elevate overall blood glucose concentration either acutely or chronically [23].

High protein diets have also been proposed to place the kidneys under increased strain. Indeed, in adults who already have chronic kidney disease, restricting protein intake was shown to decrease the risk of kidney failure and end-stage renal disease, but not all-cause death events according to a 2018 meta-analysis of RCTs [24]. However, in healthy adults—the focus of this

review—RCTs have shown no alteration of kidney function from high vs normal vs low protein diets [25]. Further, a recent meta-analysis of observational studies found an inverse correlation between protein intake and risk of developing chronic kidney disease [26].

Observational studies on protein intake and lifespan or healthspan

To gain more relevant insight into the relationship between protein intake and lifespan, there is a wealth of observational studies. At first glance, the results here seem mixed. One meta-analysis of eleven prospective cohort studies with 350,452 participants found that higher protein intake was associated with increased all-cause mortality, although removing animal protein from the analysis reversed the direction of the association [27]. Yet, a larger meta-analysis of 32 prospective cohort studies with 715,128 participants found a negative correlation between all-cause mortality and higher protein intake across total, animal, and plant protein [28].

It is plausible that certain animal-specific lipids confound these studies in favour of lower (animal) protein intakes, given that a network meta-analysis of prospective cohort studies found that replacing saturated fatty acids (SFA) with ω-3 or ω-6 poly-unsaturated (PUFA) and mono-unsaturated fatty acids (MUFA) was associated with decreased all-cause mortality [29]. Supporting the notion that the correlation between high protein diets and reduced all-cause mortality is confounded by SFAs is The Kawasaki Aging and Wellbeing Project, in which fish (low in SFA, high in PUFA) represented the predominant protein source, which found that the individuals in the top quartile of protein intake had less than half the risk of all-cause mortality than those in the lowest quartile [30].

Degree of food processing is another plausible confounder that can explain why some observational studies find a positive correlation between animal protein intake and all-cause mortality. Prior to commercial expansion, vegan or plant-based diets have historically required an emphasis on whole foods over ultra-processed foods, while many animal-protein-containing foods are highly processed. Ultra-processed foods have been recently shown, in a RCT which equated calories, protein, and fibre between groups, to drive increased fat mass retention relative to a minimally processed diet in the context of caloric restriction [31]. Further, large prospective cohort studies have shown negative outcomes for cardiovascular disease risk, cancer risk, and all-cause mortality risk from processed meat but not unprocessed meat [32,33].

Thus, it is likely that the seeming advantage of plant protein in many large prospective cohort trials is mediated by lower ultra-processed foods, lower SFAs, and higher fibre intakes, the latter also being strongly correlated with reduced all-cause mortality [34]. When compared head-to-head in RCTs, multiple meta-analyses show that isolated animal protein supplementation is superior for muscle mass and strength compared to isolated plant protein supplementation [35,36].

It is worth noting that most prospective cohort studies investigating protein intake and longevity focus on older adults to be able to follow them until death. To address the dearth of

insight for younger populations, and to focus on quality of life rather than mortality risk, a 2024 prospective cohort study studied the relationship between midlife protein intake and healthy aging, defined as "being free from 11 major chronic diseases, having good mental health, and not having impairments in either cognitive or physical function" [37]. The authors found a significant correlation between total, animal, dairy, or plant protein intake and healthy aging among 48,762 nurses under 60 years old.

Taken together, prospective cohort studies provide clear support for the notion that high protein diets improve disease and mortality risk, with the caveat that SFAs or ultra-processed foods or low fibre diets may blunt or reverse these benefits at the population level. Speculative mechanisms by which a high protein diet may negatively impact human health, such as macrophage mTOR activation, are therefore seemingly outweighed by the larger positive impacts of a high protein diet. Further, healthy kidney function is unaffected by high protein intakes, although individuals with pre-existing chronic kidney disease might be able to slow their disease progression by restricting protein intake, although their mortality risk is not increased by a higher protein intake. The preponderance of observational data supports the recommendation of a high protein diet for health, healthspan, and longevity, although precise quantitative recommendations are difficult to extract from these studies.

Optimising protein intake for muscle mass and strength

The beneficial effects of a high protein intake on healthspan and lifespan are mediated by improved body composition, enhanced muscle mass, and enhanced muscle function/strength. Meta-analyses of RCTs consistently show that higher protein intakes boost satiety and this can aid fat loss in both healthy and overweight individuals [38,39]. Meta-analyses of RCTs also consistently show that higher protein intakes support muscle mass accretion, strength gains, and the prevention of muscle atrophy during caloric restriction for healthy, overweight, or aged populations—especially in combination with resistance training [40–45]. A single exception here is a 2018 meta-analysis of RCTs by ten Haaff and colleagues which focused on the effects of protein supplementation on muscle size and function in non-frail community-dwelling elderly individuals [46].

To explain this outlier, and to extract precise protein intake recommendations from all of these meta-analyses, the remainder of this review will focus on seven relevant meta-analyses, shown in Table 1, performing re-analysis where appropriate.

Study	RCTs	Participants	Inclusion criteria	Author conclusion	Ref.
Liao et al. , 2017	17	892	Overweight or obese (mean BMI ≥ 25), with resistance training, old (mean age ≥ 60 years)	"this systematic review presents evidence that PS combined with RET effectively elicits gains in LBM, ALM, or LLM, muscular volume, and leg strength in older people, regardless of body weight"	[43]
Morton et al. , 2018	49	1863	Healthy, with resistance training, trained and untrained, young and old, ≥6 weeks duration	"Dietary protein supplementation significantly enhanced changes in muscle strength and size during prolonged RET in healthy adults."	[44]
ten Haaff et al. , 2018	36	1682	Non-frail, with and without resistance training, old (mean age ≥ 50 years), community dwelling, ≥ 4 weeks duration	"protein supplementation in nonfrail community-dwelling older adults does not lead to increases in lean body mass, thigh muscle cross-sectional area, muscle strength, or physical performance compared with control conditions, nor does it exert superior effects when added to resistance exercise training"	[46]
Tagawa et al. , 2020	105	5402	Not critically ill, with and without resistance training, young and old, positive and negative and neutral energy balance, ≥2 weeks duration	"slightly increasing current protein intake for several months by 0.1 g/kg/d in a dose-dependent manner over a range of doses from 0.5 to 3.5 g/kg/d may increase or maintain lean body mass"	[42]
Nunes et al. , 2022	66	2665	Healthy, with and without resistance training, young and old	"the evidence in this meta-analysis supports the hypothesis that additional protein ingestion (1.6 g of protein/kg/day or higher) leads to small increments in lean body mass in studies enrolling young subjects in RE training. The results on older subjects seem marginal or influenced by individual studies"	[41]
Kokura et al. , 2024	28	1989	Overweight or obese (mean BMI ≥ 25), with and without resistance training, young and old, with and without caloric restriction	"The findings from this systematic review and meta-analysis suggest that adults with overweight or obesity and aiming for weight loss can more effectively retain muscle mass through increased protein intake"	[40]
Refalo et al. , 2025	29	729	Non-elderly, non-obese, trained individuals, with resistance training, in caloric deficit, both short and long duration	"The present meta-regression [provides] quantitative support for a linear dose-response relationship between dietary protein intake and favorable FFM change"	[45]

Table 1 - Summary of meta-analyses addressing protein intake on muscle mass

Liao et al. , 2017

Liao and colleagues performed a meta-analysis of 17 RCTs entitled: "Effects of protein supplementation combined with resistance exercise on body composition and physical function in older adults" [43]. The subjects of the RCTs were elderly and overweight, averaging 73.4 ± 8.4 years old and with a BMI of 29.7 ± 5.5. The RCTs all included resistance training. Higher protein intakes combined with resistance training resulted in significantly greater gains in lean mass and strength compared to just resistance training alone.

The authors also performed valuable subgroup analyses. Firstly, they found that being obese did not change the benefit of increased protein (Figure 1A). Secondly, they found that shorter intervention periods led to greater heterogeneity in results, with improvements from protein plus resistance training becoming non-significant with interventions under 12 weeks in duration (Figure 1B). This is instructive for other meta-analyses, since many include RCTs with very short interventions. Longer interventions create more consistent effects, and these effects are in favour of higher protein.

Interestingly, when separating RCTs by sex of the participants, the researchers found no beneficial effect of increased protein for women (Figure 1C). This has led many to believe that only men stand to gain from high protein diets, yet this interpretation should be made with caution. There were only three RCTs which included women:

• One 8-week trial of resistance training elderly polymyalgia rheumatica patients supplemented the intervention group with 28 g of protein per day and found a significant increase in lean body mass as measured by for Dual-energy X-ray Absorptiometry (DXA)—the gold standard for such measurements [47].

• A second study supplemented resistance training elderly individuals with only 15 g of protein per day and found no significant improvement from protein supplementation on DXA-determined lean body mass [48]. Doses of 20-40 g are typically recommended to

sufficiently stimulate muscle protein synthesis [49]. Given that the elderly require even higher doses of protein to stimulate muscle protein synthesis to the same degree as younger populations [50,51], it is unsurprising that this trial of 15 g doses did not produce significantly greater lean mass gains.

• The third trial supplemented elderly women exercising with resistance bands with 20 g of protein per day, which may still be insufficient to stimulate muscle protein synthesis in this population, and measured lean body mass with bioelectrical impedance analysis (BIA) [52]. While BIA is easier to implement and correlates reasonably well with DXA measurements, it has been shown to be less accurate and consistently overestimate fat-free mass (FFM) and underestimate fat mass [53–55].

As such, the null results of the latter two studies can be explained by significant experimental limitations. In this instance, interpreting individual studies might be more informative than a meta-analysis of three RCTs with very heterogenous study designs. At the very least, given the preponderance of evidence that higher protein intakes offer improved outcomes for resistance training in other populations, more studies on elderly women are required before making firm conclusions that higher protein intakes are ineffective in this subgroup.

Beyond this subgroup analysis, Liao and colleagues do not offer dose-specific insights. In elderly and overweight populations, higher protein intakes are therefore recommended with no upper limit.
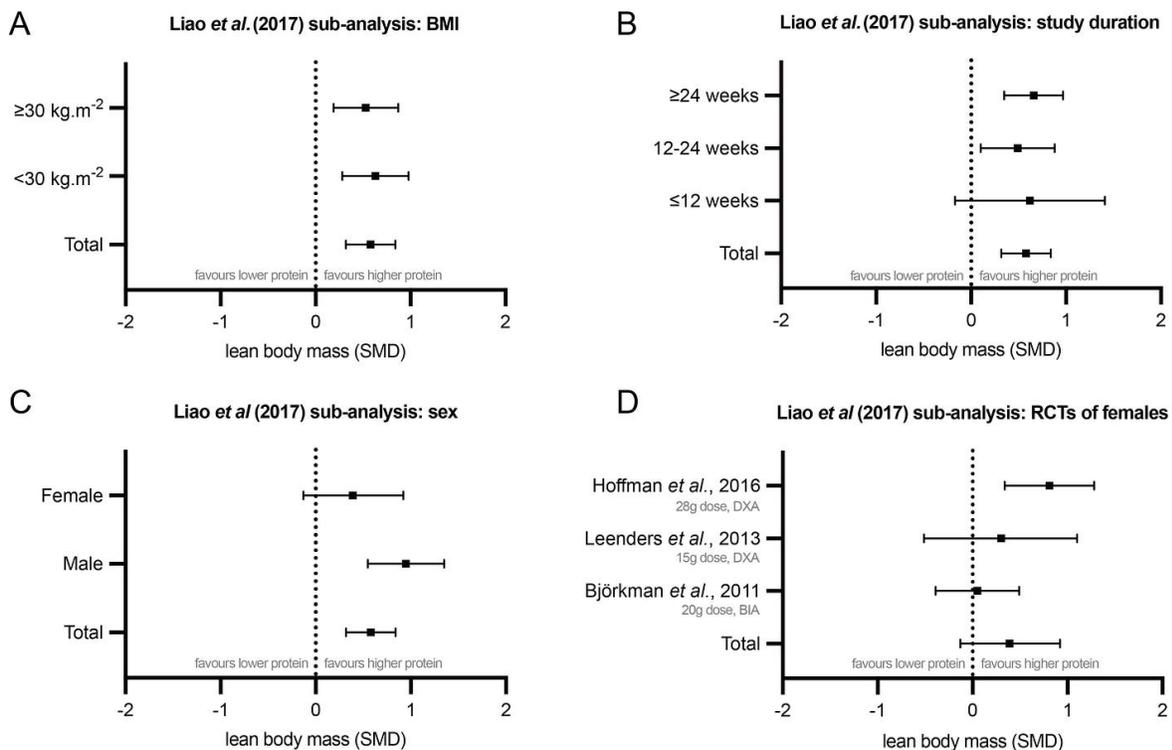

Figure 1 - Subgroup analysis of Liao et al. (2017). Effect of protein intake on lean body mass, measured in standardized mean difference (SMD), subgrouped by **A**: BMI; **B**: study duration; **C**: sex; **D**: RCT within

female subgroup. Error bars represent 95% confidence intervals. Data were extracted from Liao *et al.* in compliance with its Elsevier user license [43].

Morton et al. , 2018

While recommendations for the elderly are important, health and healthspan recommendations should target all ages. This is especially true regarding muscle mass and strength, since accumulating more during early and midlife would offset age-related losses independently of interventions late in life.

Morton and colleagues performed a meta-analysis of 49 RCTs on healthy adults of all ages with resistance training. They found that increased protein intake led to significantly greater FFM, strength, and muscle size gains compared to resistance training alone [44].

Subgroup analysis led the authors to make two additional conclusions: the benefit of higher protein decreased with age, and higher protein intakes were less effective when participants were completely untrained prior to the study.

The diminishing effect of age here is based on a univariate analysis, which showed that age was significantly inversely correlated with protein-induced improvements in FFM (β = -0.01, *p* = 0.02). Yet when multivariate meta-regression was applied, which took into account any mediating effect of protein dose, age no longer significantly affected ΔFFM outcomes (β = -0.01, *p* = 0.19). Plotting protein dose against age reveals why this is the case: RCTs on older participants tended to use smaller protein doses (Figure 2A, B). Thus, with protein dose removed as a mediator, there is no evidence that older individuals do not benefit from higher protein intakes when undertaking resistance training. Indeed, as previously mentioned, older participants likely need *even more* protein to elicit the same benefit [50,51], and future RCTs on this demographic subgroup should endeavour to test higher doses of protein supplementation.
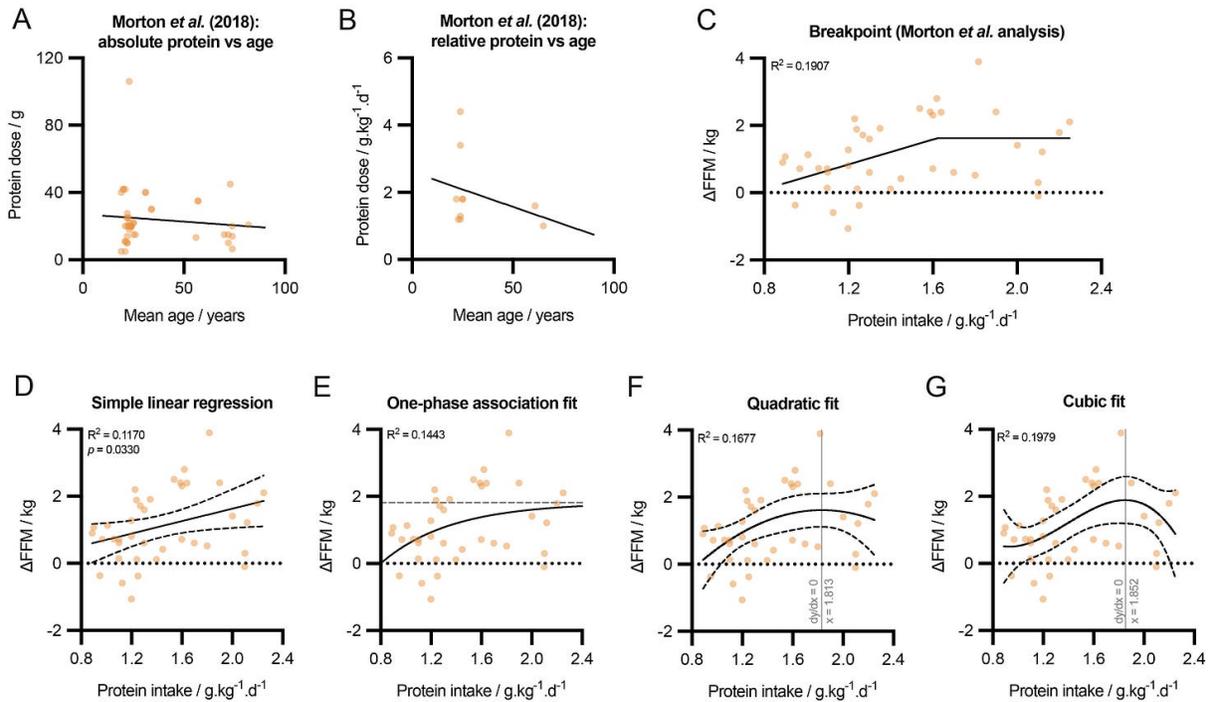
Figure 2 - Re-interpretation of Morton *et al.* (2018) via identification of mediators and alternative modelling. A-B: Negative correlation between mean age of subjects and protein intervention dose for included RCTs that declare dose in absolute terms (A) and relative terms (B). **C**: Reproduction of segmented linear regression ("breakpoint analysis") from Figure 5 of Morton *et al.* (2018). **D-G**: Alternative models for the same data ordered with increasing coefficient of determination, including linear regression (D), one-phase association (E), quadratic fit (F), and cubic fit (G). 95% confidence intervals are shown where appropriate. For polynomial curves, maxima are annotated. Data extracted from Morton *et al.* via Plot Digitizer in compliance with CC BY-NC 4.0 license (http://creativecommons.org/licenses/by-nc/4.0/) [44].

The greater benefit of higher protein intakes with concomitant resistance training in habitually trained individuals is a well-recognised phenomenon. This likely comes about since the effect size of the training alone is so large for previously untrained individuals (a phenomenon colloquially referred to as "newbie gains"), that any further benefit induced by diet is relatively small. Morton *et al.* found that the benefit of high protein intake on ΔFFM in untrained individuals was small in effect size and non-significant (+0.15 kg; 95% CI: 0.02, +0.31; p = 0.08), but large and significant in trained individuals (+1.05 kg; 95% CI: +0.61, +1.50), p<0.0001) [44]. The strong empirical evidence for this phenomenon presented by Morton and colleagues should be instructive for other meta-analyses, which often do not separate untrained from trained subjects. Given that resistance training is recommended for health and healthspan, recommendations for protein intake should be made primarily on the basis of RCTs on trained individuals.

Combining RCTs on both untrained and trained individuals, Morton *et al.* next analysed the relationship between daily protein intake and ΔFFM. They chose to model their data via segmental regression ("breakpoint analysis") which fixed a horizontal line from 1.62 g/kg/d and above (Figure 2C). They chose this model because it explained more variance (R^2 = 0.1907) than a simple linear regression (R^2 = 0.1170, p = 0.0330) (Figure 2D). This choice of model has led to

interpretations that there is no benefit of increasing protein intake beyond 1.6 g/kg/d. However, the same data can be fitted with a one-phase association curve (R^2 = 0.1443) (Figure 2E), a quadratic curve (R^2 = 0.1677) (Figure 2F), or a cubic curve (R^2 = 0.1979) (Figure 2G).

The best fitting model here is the cubic curve, which has a local maximum at 1.852 g/kg/d. Nonetheless, given that these data include both trained and untrained subjects, and the models all fit the heterogenous data quite poorly, caution should be taken before recommending optimal protein intakes from this dataset. It is also worth noting that ΔFFM is one beneficial outcome of a high protein diet. Even if protein intakes above 1.85 g/kg/d do not result in further gains in FFM, there may still be added benefit for fat loss or muscle function/strength.

ten Haaff et al. , 2018

A meta-analysis of 36 RCTs of old (>50 years old) non-frail adults both with and without resistance training was performed by ten Haaff and colleagues [46]. They posited that frail elderly adults are more likely than non-frail individuals to benefit from high protein intakes, and so sought to test non-frail populations specifically. They found no significant enhancement of lean body mass or muscle strength/function in this population either with or without resistance training. This meta-analysis stands out as the only one of the seven reviewed here to show a null result for protein supplementation.

The most obvious reason for these null results relates to the phenomenon observed in Morton *et al.* (2018) [44]: protein interventions in RCTs on older adults tend to be very low. Many of the RCTs in this meta-analysis use doses of 15 g of protein or less, which is insufficient to stimulate muscle protein synthesis in young individuals, let alone old individuals. Of those RCTs that use higher doses (~25 g), many only implement these doses three days per week. Indeed, the authors themselves admit that "the protein supplementation protocol could have been suboptimal in some studies".

The inferior protein interventions deployed by the RCTs in this meta-analysis make it difficult to form meaningful conclusions. Future RCTs of non-frail over-50s should aim to implement doses more likely to be effective (>25g per day) [56,57].

Tagawa et al. , 2020

The largest meta-analysis investigating the effects of protein intake ± resistance training on muscle mass was performed by Tagawa and colleagues, and included 105 RCTs of all non-critically ill adults over a range of dietary settings [42]. By casting such a wide net, the authors sought to impute a dose-response curve, which would inform optimal daily protein intake recommendations. They generated spline curves to model the data and determine the dose-response relationship between daily protein intake and ΔFFM or lean body mass (Figure 3). Adjusting for age, sex, intervention period, and resistance training volume, they found that increasing protein intake always resulted in greater gains in FFM—even beyond 3 g/kg/d. In individuals not engaged in resistance training, diminishing returns were observed beyond 1.3 g/kg/d, but when subjects were concomitantly engaged in resistance training, the dose-response

relationship was remarkably linear (Figure 3, middle panel).
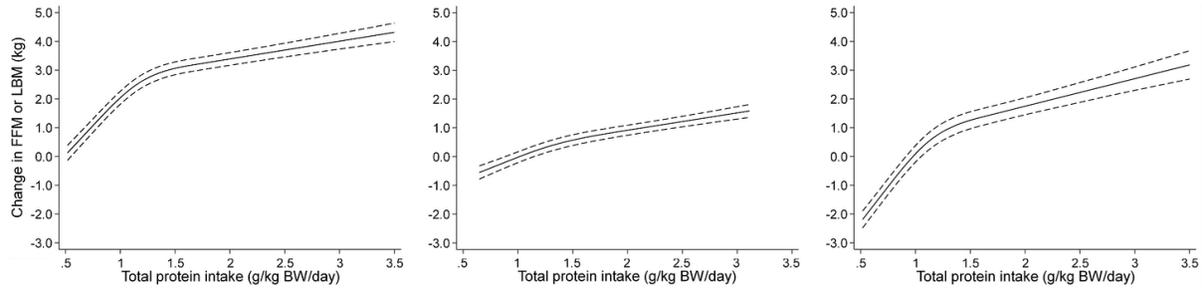

Figure 3 - Dose-response relationship between daily protein intake and change in lean body mass. Spline curves were fitted to the data after multivariate adjustment for age, sex, intervention period, and resistance training volume. From left to right: all RCTs, RCTs with resistance training, and RCTs without resistance training are modelled. Adapted from Figure 2 of Tagawa *et al.* (2020) in compliance a CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/) [42].

This dose-response model has substantially tighter confidence intervals that those generated from Morton *et al.* (2018), likely due to better adjustment for co-variates and more data (105 RCTs versus 45 RCTs). This meta-analysis offers convincing evidence that lean body mass gains are superior with a higher protein diet at all ranges of protein intake, and that concomitant resistance training maximises the benefit of increases above 1.3 g/kg/d.

Nunes et al. , 2022

The notion that higher intakes of protein across a wide range of intakes leads to greater lean body mass gains with concomitant resistance training was corroborated by a meta-analysis of 66 RCTs by Nunes and colleagues on healthy adults of all ages [41]. They found significant benefits of higher protein in resistance training individuals on lean body mass gains (SMD = +0.19; 95% CI: 0.11, 0.28) and also lower body strength gains (SMD = 0.21; 95% CI: 0.08, 0.34).

Subdividing protein intake into three strata revealed no significant benefit of protein intakes below 1.2 g/kg/d on lean body mass (SMD = -0.14; 95% CI: -0.56, 0.27), a modest and significant benefit between 1.2 g/kg/d and 1.6 g/kg/d (SMD = +0.17; 95% CI: 0.06, 0.28), and a large and significant benefit above 1.6 g/kg/d (SMD = +0.30; 95% CI: 0.17, 0.43). This three-level meta-regression directly supports the notion that RCTs where protein doses are too low are unlikely to show an added benefit of protein supplementation with resistance training on lean body mass (as is the case for many RCTs on older subjects—as discussed earlier in the context of the meta-analysis by ten Haaff and colleagues [46]). This same phenomenon was observed for strength gains, with only the highest substratum of protein intake (>1.6 g/kg/d) receiving a significant benefit from their additional protein intake (SMD = 0.40; 95% CI: 0.23, 0.57). Contrary to the assertion that there is little added value of increasing protein intake beyond 1.6 g/kg/d, this meta-analysis offers strong support that intakes above 1.6 g/kg/d are the most beneficial for resistance-training individuals.

Kokura et al. , 2024

Focusing on overweight or obese individuals aiming to lose weight, Kokura and colleagues performed a meta-analysis of 28 RCTs investigating the effect of higher protein intakes on muscle mass retention [40]. They found that higher protein intakes were significantly protective against loss of muscle mass during weight loss (SMD = +0.75; 95% CI: 0.41, 1.10). Analysing the dose-response relationship in this context of caloric restriction, they found that protein intakes below 1.0 g/kg/d were detrimental for muscle mass retention, while intakes above 1.3 g/kg/d could not only prevent loss of muscle mass, but increase muscle mass. They found no significant benefit on strength from higher protein intakes, which is unsurprising given only eight of the included RCTs included concomitant resistance training.

This meta-analysis, while focusing on overweight individuals aiming for weight loss and mostly not undergoing resistance training, adds further weight to the recommendation that higher protein intakes (of at least 1.3 g/kg/d in this case) are beneficial for lean body mass.

Refalo et al. , 2025

While most of the RCTs in the meta-analysis by Kokura and colleagues did not include resistance training, and all participants were overweight or obese, Refalo and colleagues exclusively focused on the effects of protein intake on FFM in calorically restricted non-obese individuals undertaking resistance training [45]. Further, all participants were experienced in resistance training prior to the study. These inclusion criteria make this meta-analysis of 29 RCTs highly relevant to healthy populations already following resistance training recommendations.

To model the dose-response relationship between protein intake and ΔFFM, the authors deployed a Bayesian approach to compare models. Contrary to previous indications of diminishing returns with higher protein intakes, they found that the dose-response relationship was linear with >97% probability, and that the linear model outperformed other non-linear models via Bayes Factor analysis. The benefit of higher protein for FFM was stronger in longer trials (>4 weeks), if participants had lower baseline bodyfat percentages, and in men. Including random effects, the linear model explained 55% of the variance ($R^2_{conditional}$ = 0.55) [45].

This statistically robust meta-analysis with stringent inclusion criteria corroborates the subgroup analysis on resistance training individuals by Tagawa and colleagues, which also showed a linear dose-response relationship after covariate adjustment (Figure 3) [42], but in the context of caloric restriction. Refalo and colleagues conclude that protein intakes up to 2.5 g/kg/d are associated with greater preservation of FFM during caloric restriction, and that increasing this further up to 4.2 g/kg/d (the highest dose of included RCTs) is "linearly associated with larger FFM gain".

Summary and conclusions

Governmental recommendations for protein intakes were designed to prevent deficiency, not to optimise health. The updated AMDR recommendation for protein intake provides a very wide range (0.8 – 2.8 g/kg/d), which leaves a lot of room for dispute.

Many worry that excessively high protein intakes might be harmful, or that benefits wane beyond a certain threshold, yet these concerns are not evidence-based. Evidence of harm—either via glucose control, mTOR activation in immune cells, or on kidney function—is not seen in studies of healthy humans. There is evidence that chronic kidney disease patients may be able to slow rate of disease progression by restricting protein intake, but all-cause mortality risk is not improved by doing so [24]. At the population level, vast quantities of observational data show that higher protein intakes increase healthspan and lifespan, particularly when saturated fatty acids and ultra-processed foods are accounted for or avoided.

Higher protein intakes are beneficial for satiety, fat loss, muscle gain/retention, and muscle strength/function—all of which improve quality of life, health, healthspan, and lifespan. By careful review and interpretation of seven relevant meta-analyses, this review converges on the conclusion that higher protein intakes improve muscle mass accretion (or retention in a caloric deficit) at all ranges of protein intakes for young, old, healthy, and obese populations. In non-resistance-training populations, the additional benefit beyond 1.3 g/kg/d lowers—reflecting continued but diminishing returns here [42]. For resistance-training individuals, however, multiple large, well-designed, and statistically robust meta-analyses converge on the notion that the dose-response relationship between protein intake and ΔFFM is linear [41,42,45]. There is strong evidence that higher protein intakes accentuate strength gains induced by resistance training too. In older populations, a large number of RCTs have used suboptimal protein intervention doses, which can skew meta-analyses of these studies. The well-documented necessity for higher protein doses in elderly populations should be incorporated into future RCTs of the elderly.

Since resistance training is already recommended for most people to optimise health, the optimal protein intake for a resistance-training individual should be calculated via cost-benefit analysis that assumes that health benefits scale linearly, and that minimises economic-, convenience-, and preference-based costs primarily—since there is little evidence for any health-based costs of high protein intakes. For many, this number will emerge at the upper end of the AMDR recommendation, upwards of 2.2 g/kg/d.

Methods

Search strategy and selection criteria

Meta-analyses of RCTs investigating the effects of protein on muscle mass were identified by searches of PubMed and GoogleScholar using combinations of the search terms "protein", "supplementation", "muscle mass", "lean body mass", "fat-free mass", "resistance training", "meta-analysis", and "RCT". Only meta-analyses published in English between 2015 and 2025 were included.

Data extraction, statistical analysis, and data plotting

Where data was not directly available from the main meta-analysis article or its supplementary data, Plot Digitizer (https://plotdigitizer.com/) was used to extract values from charts. This was only required for re-analysis of Morton *et al.* (2018) [44]. Re-plotting and modelling of data and all statistical analyses was performed with Prism (Version 10.6.1, GraphPad).

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