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SHORT COMMUNICATION

Increases in protein intake, protein distribution score, and micronutrient intakes in older adults in response to a whole food-based dietary intervention

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Abstract

Background Changes in nutrient intakes and protein distribution were analyzed in response to a whole food-based dietary intervention targeting high-protein meals in older adults.

Methods Community-dwelling older adults ($n = 56$; M/F, 28/28; age, 69.3 ± 4.0 years) completed a 12-week intervention after randomization to exercise only (EX, $n = 19$), nutrition only (NUTR, $n = 16$), or nutrition plus exercise (NUTR + EX, $n = 21$). NUTR and NUTR + EX followed a dietary intervention targeting ~ 0.4 g/kg of protein at each of breakfast, lunch and dinner.

Results Relative protein intake increased in NUTR (0.99 ± 0.34 to 1.43 ± 0.39 g/kg, $P < 0.001$) and NUTR + EX (0.90 ± 0.20 to 1.57 ± 0.49 g/kg, $P < 0.001$). Intakes of cholesterol, B vitamins, selenium and iodine were increased in both NUTR and NUTR + EX ($P < 0.05$ for all).

Conclusion This dietary intervention was effective at increasing daily protein intake and achieving an even distribution pattern. Changes in micronutrient intake were marked, and reflect the increase in consumption of animal-derived protein-rich food sources.

Keywords Animal · Dairy · Exercise · Meat · Protein · Protein distribution · Skeletal muscle

Introduction

Habitual protein intake tends to decline with advancing age [1], and in older adults (≥ 65 years), intakes are typically below the currently recommended daily protein intake of at least 1.0–1.2 g/kg for this population [2, 3]. Moreover, daily protein intake typically follows a 'skewed' distribution pattern in Western society [1, 4]. Guidelines to maximize postprandial anabolism in skeletal muscle in older adults are suggested on a per meal basis to include ≥ 2.5 g of the essential amino acid leucine within a protein dose of ≥ 0.4 g/kg, and to follow an 'even' distribution throughout the day [5]. There is increasing interest in protein-rich dietary interventions focusing on whole foods rather than powdered supplements for the provision of additional dietary protein [6]. However, there has been little investigation of the effect of such an intervention on overall nutrient intake patterns.

We recently reported a randomized trial in community-dwelling older adults comparing the effects of a whole food-based dietary intervention targeting high-protein, leucine-rich meals, in the absence or presence of concurrent aerobic and resistance exercise training, on outcomes related to muscle strength, physical function and body composition [7]. The present short communication is a secondary analysis of changes in energy, macronutrient and micronutrient intakes, and protein distribution consequent to this intervention.

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Materials and methods

Study design

A parallel group, pre-post-design comprising a 12-week intervention was performed in medically stable men and women aged ≥ 65 years [7]. Participants ($n = 63$) were randomly assigned to one of three groups: concurrent aerobic and resistance exercise training only (EX), nutrition only (NUTR), and nutrition plus concurrent aerobic and resistance exercise training (NUTR + EX). Five participants from NUTR (~ 24%) were lost to follow-up or discontinued the dietary intervention, and two participants from EX (~ 10%) failed to maintain the exercise training frequency, leaving a final n size of 56 (EX, $n = 19$; NUTR, $n = 16$; NUTR + EX, $n = 21$) (Supplemental Fig. 1; Supplemental Table 1). The details of the exercise training intervention are described in detail elsewhere [7].

Dietary intervention

The dietary intervention targeted an increase in protein intake by providing meal and recipe suggestions using a whole food approach (i.e. without powdered protein supplements and oral nutrition solutions) to achieve ~ 25–35 g (~ 0.4 g/kg) of protein per meal. Each of these protein-rich meal recommendations also aimed to provide ~ 3 g of leucine. Participants from NUTR and NUTR + EX initially attended a briefing session in groups of 4–6 participants during which the dietary intervention was explained in detail. Participants were instructed to consume a protein-rich meal at breakfast, lunch and dinner every day for the 12-week period, and in NUTR-EX, for one of these protein-rich meals to be within 60 min of the end of each training session. Participants were asked to consume the specified portion in one sitting, and were asked not to split the portion over different eating occasions (EOs). Identical meal and recipe suggestions were provided fortnightly by email to the participants in NUTR and NUTR + EX. These suggestions were informed by the USDA Food Composition Database, by translating food combinations into user-friendly portion sizes, meals and recipes. All of these protein-rich suggestions were based on animal-derived foods, namely meat, fish, eggs and dairy. No restriction was placed on daily calorie consumption (i.e. energy intake was ad libitum), nor was there instruction to substitute other foods with these protein-rich portions.

Compliance with the dietary intervention was monitored using a tick-box checklist diary completed per meal on a daily basis. Because of attendance at the supervised exercise sessions, contact with the NUTR + EX participants was weekly and informal, whereas contact with the NUTR participants was maintained formally with a fortnightly phone call to encourage participants to comply with the intervention. The EX group were asked to not make any changes to their habitual dietary intake for the duration of the study.

Food diary analysis

All participants completed a 3 day (2 weekdays, 1 weekend day) portion-estimate food diary in the week before starting the intervention (week 0, PRE), and in weeks 6 (MID) and 12 (POST) of the intervention. Participants were asked to estimate food weight based on food packaging, and if this was not possible, to quantify and describe food size as accurately as possible. For mixed meals and recipes, participants were asked to record each meal component and/or ingredient separately. Time of day of consumption was also recorded. A member of the research team (M.H.) followed-up with brief interviews whenever there was doubt about the details of entries into a given food diary.

Food diaries were analyzed using Nutritics Dietary Analysis Software (Nutritics, Ireland). The entry for each day was separated into EOs, defined as any energy-containing food or fluid separated by more than 30 min. For protein intake and distribution, EOs were assessed to determine: (1) Protein Distribution Score^{20} (PDS^{20})—the number of EO per day containing over 20 g of protein; and (2) Protein Distribution Score$^{\mathrm{IPT}}$ (PDS$^{\mathrm{IPT}}$)—the number of EO per day at or above the individual protein target (IPT) of 0.4 g × body mass (kg). A score of 1 was given to each meal reaching the 20 g protein and 0.4 g/kg body mass protein threshold for PDS^{20} and PDS$^{\mathrm{IPT}}$, respectively, and then averaged over the 3 days recorded at each time point. The PDS scoring system is based on the method of MacKenzie et al. [8] as we have previously described [1], with 0.4 g/kg values for IPT being representative of the recommended per meal protein target to maximize the anabolic response in skeletal muscle in older adults [5].

Statistical analyses

Statistical analysis was performed using SPSS v23 (IBM Corp, Armonk NY, USA). All data are presented as mean ± SD. The differences from PRE over time within groups, and the differences between treatment groups at the same time points were investigated using a two-way (group*time) mixed analysis of variance (ANOVA). When a group*time interaction effect was indicated, post hoc testing was performed with Tukey's correction, and multiplicity-adjusted P values are reported for the respective comparisons between (EX, NUTR, NUTR + EX) and within (PRE, MID, POST) groups. The threshold for statistical significance was set at $P \leq 0.05$.

Results

Energy and macronutrient intake

There was no change in any aspect of dietary intake in EX. In NUTR and NUTR + EX, the dietary intervention was successful in increasing daily protein intake ($P < 0.001$ for both groups) (Table 1), and consequently energy intake ($P < 0.01$ for both groups) (Supplemental Table 2). The directional increases in daily fat intake of ~ 15 g/day in both NUTR and NUTR + EX did not reach statistical significance, but the combined effects of increased protein and fat intake resulted in the average calorie intake increasing by ~ 300–350 kcal/day in NUTR, and ~ 400–500 kcal/day in NUTR + EX, respectively (both $P < 0.05$ for both MID and POST) (Supplemental Table 2).

Protein distribution by EO and PDS

In both NUTR and NUTR + EX, protein intakes at breakfast, lunch and dinner were each increased from PRE to MID ($P < 0.01$ for both groups), and maintained from MID to POST. The same general patterns of protein intake in absolute values (Fig. 1) were also observed in relative terms (Supplemental Table 3). PDS for meals reaching the 20 g and 0.4 g/kg protein thresholds are presented in Table 1. The dietary intervention was successful in increasing PDS^{20} and PDS^{IPT} in NUTR and NUTR + EX from PRE to MID, and then maintaining these scores from MID to POST (Table 1).

Dietary components and micronutrients

In NUTR, intakes of cholesterol, vitamin B2 and B12, selenium and iodine were increased at MID and POST ($P < 0.05$ for all), whereas intakes of lactose and vitamins B3, B5 and B7 were increased at POST only ($P < 0.05$ for all). In NUTR + EX, intakes of lactose, saturated fat, monounsaturated fats, trans-fatty acids, cholesterol, all B vitamins, vitamin D, sodium, potassium, chloride, calcium, phosphorus, magnesium, zinc, selenium and iodine were increased at MID and POST ($P < 0.05$ for all). There were no changes in micronutrient intakes in EX at any time point (Table 2).

Discussion

Prior to the intervention, the participants' habitual daily protein intake relative to body mass was 1.14 ± 0.35 g/kg, 0.99 ± 0.34 g/kg, and 0.90 ± 0.20 g/kg for EX, NUTR and NUTR + EX, respectively, which are similar intakes to those reported previously in community-dwelling older adults in Ireland [1]. While these intakes exceed the current population reference intake (PRI) of 0.83 g/kg for protein intake in adults, there is a growing consensus that daily protein requirements for older adults are at least 1.0–1.2 g/kg [3] and ≥ 1.2 g/kg in older adults undertaking regular exercise [2, 5].

The dietary intervention was successful in increasing daily protein intake at MID protein by 63% and 79% in NUTR and NUTR + EX, respectively, i.e. to 1.43 ± 0.39 g/kg NUTR, and to 1.57 ± 0.49 g/kg in NUTR + EX, which was maintained for the remainder of the intervention. This suggests that an initial information session and fortnightly

Table 1 Macronutrient intakes in quantities relative to body mass (g/kg), and protein distribution scores (PDS)

	CHO (g/kg)	Fat (g/kg)	Protein (g/kg)	PDS^{20}	PDS^{IPT}
EX					
PRE	2.6 ± 0.7	1.0 ± 0.4	1.14 ± 0.35	1.65 ± 0.67$^{\#}$	1.05 ± 0.67
MID	2.5 ± 0.8	1.0 ± 0.4	1.10 ± 0.30$^{\#\dagger}$	1.58 ± 0.60$^{\#\dagger}$	0.91 ± 0.54$^{\#\dagger}$
POST	2.6 ± 0.8	0.9 ± 0.3	1.05 ± 0.28$^{\#\dagger}$	1.49 ± 0.61$^{\#\dagger}$	0.81 ± 0.39$^{\#\dagger}$
NUTR					
PRE	2.3 ± 0.9	0.9 ± 0.3	0.99 ± 0.34	1.50 ± 0.54	0.92 ± 0.66
MID	2.0 ± 0.6	1.0 ± 0.4	1.52 ± 0.45***	2.69 ± 0.48***	1.94 ± 0.79***
POST	2.1 ± 0.8	1.0 ± 0.4	1.43 ± 0.39**	2.65 ± 0.56***	1.81 ± 0.85***
NUTR + EX					
PRE	2.1 ± 0.7	0.8 ± 0.3	0.90 ± 0.20	1.14 ± 0.52	0.68 ± 0.40
MID	2.1 ± 0.6	1.0 ± 0.3	1.59 ± 0.28***	2.68 ± 0.41**	2.00 ± 0.63***
POST	2.0 ± 0.7	1.0 ± 0.3	1.59 ± 0.51***	2.60 ± 0.68***	2.05 ± 0.60***

Data are mean ± SD. CHO, carbohydrate; EI, energy intake. Differences within groups compared to PRE are indicated by $^{**}P < 0.01$, and $^{***}P < 0.001$ for the annotated time-point. Differences between groups are indicated by $^{\#}$ to denote differences from NUTR + EX, and † to denote differences from NUTR, for the annotated time-point (both $P < 0.05$)

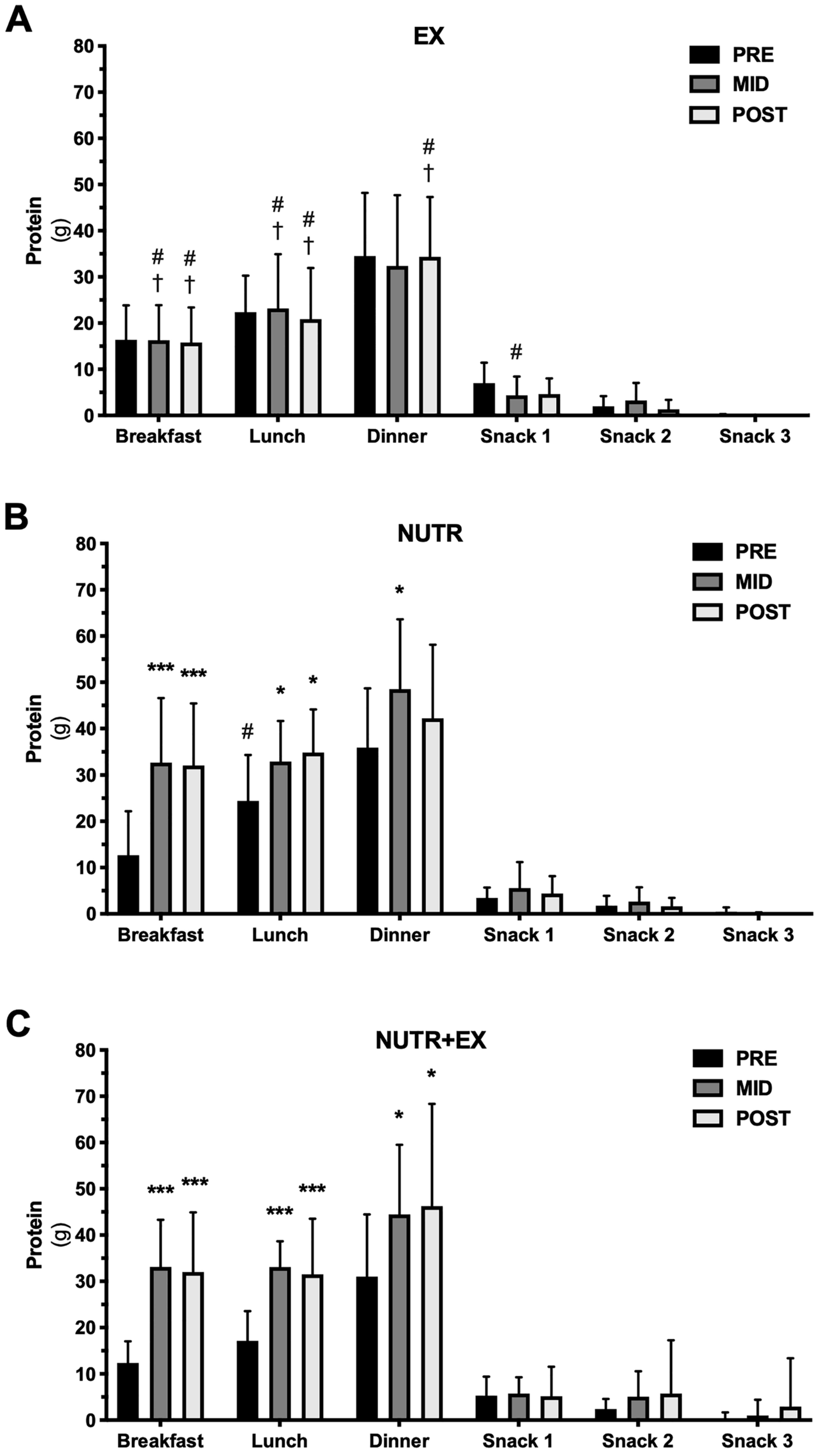

Fig. 1 Protein intake at breakfast, lunch, dinner and snacks at PRE (week 0), MID (week 6) and POST (week 12) in EX (**A**), NUTR (**B**), and NUTR + EX (**C**). Data are mean ± SD. Differences within groups compared to PRE are indicated by $*P < 0.05$, $**P < 0.01$ and $***P < 0.001$. Differences between groups are indicated by # to denote differences from NUTR + EX, and † to denote differences from NUTR, for the annotated time-point (both $P < 0.05$).

Table 2 Dietary nutrient profile and micronutrient intakes

	EX			NUTR			NUTR + EX		
	PRE	MID	POST	PRE	MID	POST	PRE	MID	POST
Carbohydrate									
Starch (g)	108.3 ± 23.9	98.9 ± 23.5	109.9 ± 44.4	101.5 ± 31.2	81.3 ± 30.2	85.8 ± 32.9	90.1 ± 35.0	83.0 ± 35.5	87.4 ± 30.2
Sugars (g)	76.7 ± 21.1	73.6 ± 38.3	74.3 ± 37.9	71.9 ± 31.4	63.0 ± 31.2	69.4 ± 30.1	59.4 ± 23.1	66.4 ± 21.6	67.2 ± 20.5
Free Sugars (g)	22.2 ± 12.9	20.6 ± 13.8	26.3 ± 16.5	29.0 ± 18.8	19.9 ± 10.3	24.7 ± 13.8	19.1 ± 12.3	19.6 ± 10.7	16.9 ± 10.1
Lactose (g)	8.1 ± 6.5	7.9 ± 7.0	7.8 ± 6.9	7.9 ± 6.3	16.0 ± 13.2	17.5 ± 13.9*$^{\#}$	9.0 ± 4.6	18.7 ± 10.0*$^{\#}$	19.2 ± 8.5*$^{\#}$
Fibre (g)	20.9 ± 7.5	19.4 ± 7.8	19.8 ± 7.9	17.4 ± 5.9	15.3 ± 6.1	15.0 ± 5.1	14.3 ± 3.8	15.4 ± 3.7	15.6 ± 4.0
GL	103 ± 22	96 ± 29	106 ± 34	100 ± 31	81 ± 28	90 ± 31	88 ± 34	83 ± 28	89 ± 27
Fat									
Saturated Fat (g)	26.2 ± 9.1	24.5 ± 6.9	24.4 ± 8.1	25.8 ± 9.6	31.4 ± 13.7	31.8 ± 15.7	21.9 ± 9.9	28.0 ± 11.3*	29.0 ± 8.0*
MUFAS (g)	24.7 ± 8.3	24.5 ± 12.1	24.3 ± 7.1	22.2 ± 8.6	26.4 ± 9.5	27.0 ± 11.3	18.7 ± 6.2	24.8 ± 8.4*	26.1 ± 6.8*
PUFAS (g)	10.9 ± 5.1	11.3 ± 8.7	11.1 ± 5.2	10.1 ± 3.5	9.5 ± 3.7	10.2 ± 4.4	8.7 ± 3.8	9.3 ± 3.0	11.2 ± 3.5
Omega 3 (g)	1.4 ± 1.1	1.9 ± 2.1	1.8 ± 1.6	1.4 ± 1.0	1.4 ± 1.1	1.9 ± 1.6	1.2 ± 0.8	1.4 ± 1.1	2.1 ± 1.5*
Omega 6 (g)	5.1 ± 3.8	5.2 ± 5.9	5.0 ± 3.5	4.9 ± 2.8	5.2 ± 2.6	5.4 ± 2.8	4.8 ± 3.2	4.6 ± 2.0	5.3 ± 1.7
Trans-fatty acids (g)	1.0 ± 0.6	0.9 ± 0.5	0.9 ± 0.5	0.9 ± 0.4	1.2 ± 0.7	1.3 ± 0.8	0.7 ± 0.5	1.2 ± 0.6*	1.2 ± 0.5*
Cholesterol (mg)	261 ± 106	269 ± 95.8	253 ± 115	293 ± 175	497 ± 221*$^{\#}$	475 ± 216*$^{\#}$	246 ± 79.7	447 ± 149.9*$^{\#}$	464 ± 152*$^{\#}$
Micronutrients									
Vitamin A (µg)	1519 ± 1294	759 ± 447	794 ± 442	990 ± 620	1077 ± 623	768 ± 420	743 ± 559$^{\#}$	842 ± 482	928 ± 983
Vitamin C (mg)	78 ± 48	83 ± 43	81 ± 36	60 ± 41	80 ± 54	74 ± 50	55 ± 33	81 ± 43*	81 ± 40
Vitamin D (µg)	3.7 ± 3.1	4.0 ± 2.5	4.3 ± 3.3	4.6 ± 2.8	5.8 ± 4.2	7.0 ± 5.1	2.9 ± 1.9	5.5 ± 3.8*	8.2 ± 5.4*$^{\#}$
Vitamin E (mg)	7.7 ± 3.8	7.7 ± 5.3	7.6 ± 3.5	7.7 ± 2.9	7.2 ± 3.1	7.1 ± 2.9	6.4 ± 3.9	7.5 ± 3.1	7.8 ± 3.0
Vitamin K1 (µg)	44 ± 81	26 ± 30	19 ± 18	15 ± 15	34 ± 35	22 ± 33	11 ± 8	35 ± 34*	34 ± 46
Vitamin B1 (mg)	1.5 ± 0.4	1.5 ± 0.5	1.6 ± 0.8	1.4 ± 0.6	1.7 ± 0.7	1.8 ± 0.7	1.3 ± 0.4	1.7 ± 0.4*	1.7 ± 0.6
Vitamin B2 (mg)	1.6 ± 0.7	1.5 ± 0.5	1.5 ± 0.6	1.3 ± 0.5	2.2 ± 1.0*$^{\#}$	2.3 ± 1.1*$^{\#}$	1.2 ± 0.4	2.2 ± 0.5*$^{\#}$	2.4 ± 0.6*$^{\#}$
Vitamin B3 (mg)	37 ± 10	37 ± 9	34 ± 12	34 ± 10	46 ± 15	46 ± 18*	29 ± 9$^{\#}$	43 ± 13*	50 ± 17*$^{\#}$
Vitamin B5 (mg)	5.3 ± 1.3	5.2 ± 1.3	4.9 ± 1.3	4.9 ± 1.7	7.1 ± 2.6$^{\#}$	7.2 ± 2.7*$^{\#}$	4.6 ± 1.6	6.7 ± 1.5*$^{\#}$	7.5 ± 1.8*$^{\#}$
Vitamin B6 (mg)	2.0 ± 0.6	1.9 ± 0.6	1.9 ± 0.7	1.7 ± 0.6	2.3 ± 1.0	2.2 ± 0.9	1.5 ± 0.5$^{\#}$	2.0 ± 0.5*	2.3 ± 0.8*
Vitamin B7 (µg)	41 ± 18	37 ± 22	33 ± 10	28 ± 11$^{\#}$	43 ± 17	43 ± 18*	26 ± 6$^{\#}$	44 ± 13*	45 ± 11*$^{\#}$
Vitamin B9 (µg)	250 ± 81	251 ± 82	237 ± 97	187 ± 57$^{\#}$	238 ± 102	226 ± 92	195 ± 77	242 ± 58*	263 ± 84*
Vitamin B12 (µg)	6.7 ± 6.4	5.3 ± 2.7$^{\#}$	5.2 ± 2.8$^{\#}$	5.3 ± 2.8*	9.5 ± 5.0*$^{\#}$	9.6 ± 5.2$^{\#}$	4.4 ± 1.6	8.8 ± 3.1*$^{\#}$	11.3 ± 4.9*$^{\#}$
Sodium (mg)	1790 ± 502	1653 ± 434	1776 ± 502	1825 ± 785	2166 ± 734	2397 ± 1013	1491 ± 542	2250 ± 816*$^{\#}$	2184 ± 809*
Potassium (mg)	2885 ± 773	2886 ± 943	2919 ± 980	2503 ± 694	3164 ± 1198	3084 ± 1093	2186 ± 468$^{\#}$	3120 ± 653*	3404 ± 762*
Chloride (mg)	3157 ± 899	2806 ± 744	2698 ± 662	2923 ± 1146	3423 ± 1120	3707 ± 1484	2408 ± 962	3527 ± 1251*	3394 ± 1021*$^{\#}$
Calcium (mg)	902 ± 270	882 ± 479	889 ± 433	805 ± 297	1091 ± 527	1140 ± 600	657 ± 192$^{\#}$	1166 ± 341*	1179 ± 279*
Phosphorus (mg)	1365 ± 269	1368 ± 367	1354 ± 438	1217 ± 396	1732 ± 630$^{\#}$	1746 ± 680*	1129 ± 244$^{\#}$	1727 ± 298*$^{\#}$	1872 ± 451*$^{\#}$

Table 2 (continued)

	EX			NUTR			NUTR + EX		
	PRE	MID	POST	PRE	MID	POST	PRE	MID	POST
Magnesium (mg)	304 ± 89	324 ± 149	317 ± 133	$243 \pm 72^{\#}$	328 ± 187	339 ± 157	$227 \pm 51^{\#}$	325 ± 118*	331 ± 122*
Iron (mg)	12.5 ± 5.2	16.4 ± 24.6	16.9 ± 22.2	9.3 ± 2.7	10.8 ± 3.5	10.6 ± 4.0	8.9 ± 2.6	10.3 ± 2.3	12.0 ± 3.7
Zinc (mg)	10.0 ± 3.4	9.7 ± 4.5	9.8 ± 4.5	8.6 ± 3.8	11.7 ± 5.0	10.9 ± 4.9	$7.1 \pm 2.2^{\#}$	11.5 ± 2.8*	12.0 ± 4.3*
Copper (mg)	1.5 ± 1.0	1.3 ± 0.9	1.3 ± 0.7	1.0 ± 0.3	1.0 ± 0.4	1.0 ± 0.4	0.8 ± 0.2	1.1 ± 0.3	1.1 ± 0.5
Manganese (mg)	3.8 ± 1.4	4.0 ± 2.2	4.0 ± 2.2	3.0 ± 1.1	2.7 ± 1.0	2.7 ± 1.2	3.0 ± 1.2	2.9 ± 1.1	2.8 ± 1.0
Selenium (µg)	53 ± 22	52 ± 18	48 ± 18	48 ± 19	$77 \pm 27^{*\#}$	$76 \pm 36^{*\#}$	45 ± 16	$70 \pm 27^{*\#}$	$77 \pm 29^{*\#}$
Iodine (µg)	138 ± 70	121 ± 53	127 ± 101	117 ± 66	$250 \pm 144^{*\#}$	$224 \pm 132^{*\#}$	141 ± 68	$250 \pm 92^{*\#}$	$268 \pm 89^{*\#}$
Other									
PRAL	9 ± 14	7 ± 19	6 ± 16	13 ± 13	$33 \pm 14^{*\#}$	$33 \pm 19^{*\#}$	14 ± 12	$31 \pm 12^{*\#}$	$34 \pm 16^{*\#}$

GL glycaemic load, *MUFAs* monounsaturated fatty acids, *NSP* non-starch polysaccharides, *PRAL* potential renal acid load, *PUFAs* poly-unsaturated fatty acids

Data are mean ± SD. Differences within groups compared to PRE are indicated by $^{*}P < 0.05$. Differences between groups are indicated by $^{\#}$ to denote differences from EX group for the annotated time-point ($^{\#}P < 0.05$)

meal/recipe newsletters and follow-up phone calls was sufficient contact time to achieve compliance to such a dietary intervention in this population. Although NUTR + EX participants were also involved in the exercise intervention and, therefore, received additional informal support during the exercise sessions, similar effects of the intervention were seen in both groups. However, there were five dropouts from NUTR (two of whom were issues unrelated to the study protocol) compared to none from NUTR + EX. We did not collect data formally on the ease or difficulty with which the participants followed the dietary intervention, but anecdotally, many participants reported verbally to be having difficulty with consuming three of the prescribed protein portions per day. Indeed, those three dropouts in NUTR were due to difficulties with appetite preventing consumption of the prescribed intakes.

Across all groups, pre-intervention protein intake followed a skewed pattern across meals with breakfast, lunch and dinner accounting for 18%, 28%, and 45% of protein intake, respectively. The distribution of protein transitioned from skewed at PRE to even at MID and POST as evidenced by increases in scores for PDS^{20} and PDS^{IPT}. The average protein intakes at breakfast, lunch and dinner increased to ≥ 0.4 g/kg per meal in NUTR and NUTR + EX for each group as a whole. The PDS^{IPT}, however, counts the number of meals per day on a per individual basis that reached the target of ≥ 0.4 g/kg protein per meal, a threshold that more specifically reflects the goal of maximizing postprandial anabolism in skeletal muscle in older adults [5]. Notably, the PDS^{IPT} revealed that not all of the three main meals reached this threshold when analyzed on a per individual basis, but nonetheless there was an improvement in PDS^{IPT} in both dietary intervention groups from ~ 0.7–0.9 up to ~ 2.0, i.e. two meals per day of ≥ 0.4 g/kg protein per meal.

Recent analyses from the multi-country PROMISS (PREvention Of Malnutrition In Senior Subjects in the EU) study demonstrates that higher protein intake (≥ 1.2 g/kg) protects, in a dose-dependent manner, against declines in physical function (walking speed) over up to 8.5 years of follow-up in a cohort of ~ 5500 adults aged ≥ 55 years [9], yet prevalence of daily protein intake below the recommended 1.0 g/kg, and 1.2 g/kg cut-off values are ~ 47% and ~ 71%, respectively, in a similar cohort [10]. In other studies, a skewed protein distribution pattern was associated with an increase in incidence of frailty [11], while the daily consumption of one or two main meals over an "anabolic threshold" of 30 g protein per EO was positively associated with greater lean body mass and strength in older adults [12].

Whether such observations are due to the protein distribution pattern, or the number of EOs that exceed an anabolic threshold regardless of distribution pattern, remains to be fully established, especially because postprandial anabolism in skeletal muscle does not always differ between even compared to skewed distribution patterns in older adults [13]. Because of the generally lower daily intake of protein, and higher anabolic threshold in older adults, prescribing an even distribution of protein may paradoxically result in less EOs per day reaching the anabolic threshold for this population [4, 13]. Therefore, there is interest in whether personalized dietary advice should emphasize an even distribution (e.g. 20 g protein per meal) or a 'peak' protein intake (e.g. targeting at least one EO per day providing 35–45 g protein [14]. In a recent 4-week study, both approaches were shown to be acceptable to older adults, and on average resulted in similar increases in daily protein intake of ~ 20–30 g [14]. Whether either pattern is more effective over the longer term and/or in support of exercise training remains to be investigated. In particular, whether higher protein intakes at certain EOs will influence subsequent food intake, and whether higher protein diets are feasible because of reduced appetite, dislike of certain protein-dense foods, or the inability to masticate protein-rich foods such as meat [13].

To attain the desired increase in protein intakes, the unique aspect of this study was the consumption of whole foods. Animal-derived foods are considered to be a better source of higher quality protein when compared to plant-derived foods [5, 6]. However, fat intake increased by 22–31% across time-points in NUTR and NUTR + EX due to the participants increasing consumption of foods that are relatively high in fat, such as eggs, dairy, oily fish and red meat, all of which were encouraged in the dietary intervention. Consequently, there were increases in lactose reflecting the increase in dairy consumption, whereas increases in dietary cholesterol and saturated fat intakes reflect these increases in eggs and meat consumption. Moreover, there were marked increases in B vitamins, vitamin D, selenium and iodine among others, suggesting that increasing protein intake through animal-derived whole foods increases the micronutrient content of the diet as a reflection of these foods as previously suggested [15].

Conclusions

A dietary intervention targeting a high daily protein intake and ~ 3 g leucine at breakfast, lunch and dinner was effective at increasing daily protein intake and achieving an even protein distribution pattern in community-dwelling older adults. The increase in PDS^{IPT} indicated that participants were consuming ≥ 0.4 g/kg per meal of high-quality protein twice daily on average as a result. Consequent to the change in food intake to achieve these goals was an increase in daily energy intake, and consuming the additional dietary protein exclusively from animal-derived protein-rich whole food sources resulted in marked increases in selected micronutrient intakes reflective of these foods.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40520-021-02009-4.

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Author contributions MH: conceptualization; data curation; formal analysis; investigation; methodology; project administration; roles/writing—original draft. JT: data curation; formal analysis; investigation; methodology; project administration. BE: conceptualization; formal analysis; funding acquisition; methodology; project administration; supervision; validation; roles/writing—original draft; writing—review and editing. All authors approved the final version of the manuscript.

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Declarations

Conflict of interest BE was formerly (in the past 36 months) funded under the Glycemic Management pillar of the Enterprise Ireland-funded technology centre Food for Health Ireland, whose focus is on the potential benefits of dairy ingredients for human health. BE is presently funded under the Health pillar of the Enterprise Ireland-funded technology centre Meat Technology Ireland, whose focus is on the potential benefits of meat for human health. BE is presently funded by the Marine Institute Ireland, a State agency responsible for marine research, technology development and innovation, for a project focused on the potential benefits of a fish protein hydrolysate on muscle health in older adults. The other authors have no conflict of interest, financial or otherwise, to declare.

Statement of human and animal rights Ethical approval was granted by the University College Dublin Human Research Ethics Committee (permit: LS-17-22-Timmons-Egan), and the study was conducted in accordance with the *Declaration of Helsinki*.

Informed consent All participants provided their written informed consent prior to commencing participation in the study.

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