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Original Contribution

A target trial emulation of adherence to Canada's food guide 2019 recommendations in older adults

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Abstract

The 2019 Canada's Food Guide (CFG) may not be tailored for older adults, since it provides universal recommendations. In community-dwelling adults aged 67-84 years and compared with habitual diet and physical activity, our objective was to estimate the 3-year difference in muscle strength, physical function, cardiometabolic health, and cognitive health score according to adherence to CFG recommendations (CFG), enhancements with additional protein foods (CFG-PRO), physical activity (PA), and both (CFG-PLUS). Longitudinal non-experimental data from the NuAge study (2003-2008 in Québec, Canada) were used to emulate a 3-year target trial. Data were collected at annual in-person follow-up visits. The hypothetical interventions were modeled using the parametric g-formula assuming no unmeasured confounding, no measurement error, and correct models. Totally, 1561 participants were eligible. Compared with no intervention, adherence to the CFG intervention would have increased quadriceps strength by 0.8 kg (95%CI: 0.0, 1.7), walking speed by 0.03 m/s (95%CI: 0.00, 0.05) and reduced waist circumference by 1.0 cm (95%CI: −1.7, −0.3). Estimates were similar for the CFG-PRO intervention. Compared with CFG alone, the CFG-PLUS intervention improved to a greater extent walking speed (vs. CFG, +0.06 m/s; 95%CI: 0.03, 0.08) and waist circumference (vs. CFG, −0.8 cm; 95%CI: −1.5, −0.2). Under strong assumptions, compared with no intervention leading to declines in most outcomes, adherence to CFG recommendations over 3 years would have attenuated declines in strength and walking speed in older adults. Greater benefits were achieved when protein food intake and physical activity were increased in addition to CFG adherence.

Key words older persons, diet quality, causal inference, nutritional epidemiology, muscle strength, physical function, cardiometabolic health

Introduction

Canada's Food Guide (CFG) was revised in 2019 to "promote healthy eating and overall nutritional well-being" based on the latest evidence (1). More precisely, the underpinning literature for CFG focuses on chronic disease reduction such as cancer, cardiovascular disease, and type 2 diabetes (2). The recommendations are mostly qualitative (eg, "eat more of …"), focus on plant-based food sources (ie, vegetables and fruits, whole-grain foods, plant-based protein foods, unsaturated fats and oils) and are depicted using a plate (1). CFG recommendations are universal to all individuals aged 2 years and older (1).

In Canada, the proportion of adults aged 65 years and older has been increasing rapidly to 19.5% in 2025 (3). Older adults are more vulnerable to inadequate dietary intakes due to social and physiological changes (4). For example, one-third of community-dwelling older adults are at nutritional risk (5, 6). In turn, older adults affected by malnutrition have an increased risk of frailty (7) and sarcopenia (8), which affects their autonomy and increases their risk of institutionalization (9). Evidence to date supports the adequacy of CFG recommendations for cardiovascular disease prevention (10). Yet, their appropriateness for fulfilling nutritional requirements and contributing to muscular and cognitive health, which are key health outcomes among older adults to maintain autonomy (8, 11), has not been documented comprehensively. Data from the 2015 Canadian Community Health Survey (CCHS)—Nutrition showed that high adherence to CFG recommendations on healthy food choices was insufficient to mitigate calcium and folate inadequacy, and insufficient to support optimal protein intakes, in older adults (12). A growing consensus also supports higher than recommended protein intakes for older adults, such as a recommended daily intake of 1.0 to 1.2 g/kg (13). Adherence to CFG recommendations may be insufficient to mitigate the substantial inadequacy

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Table 1 Emulation of a lifestyle intervention target trial using non-experimental data from the NuAge study: eligibility, intervention, assignment[a].

Trial component	Target trial specification	Target trial emulation using NuAge data
Eligibility criteria	NuAge inclusion criteria: individuals aged 67-84 years; living in Montreal, Laval, or Sherbrooke; not cognitively impaired, free of disabilities in activities of daily living. Exclusion criteria: class II heart failure, chronic obstructive pulmonary disease requiring home oxygen therapy or oral steroids, inflammatory digestive diseases, and cancer treatment in the past 5 years.	Same. Participants were also required to have complete baseline dietary assessment (at least one 24-hour recall with 500 kcal or more and FFQ) and baseline covariate data.
Intervention[b]	Each individual would be assigned to 1 of the 5 following strategies: (1) control group without intervention (habitual diet and physical activity, ie, typical North American); (2) adherence to Canada's Food Guide recommendations on healthy food choices; (3) same as (2) but including a reformulation with higher intake of protein foods; (4) physical activity alone without diet intervention; (5) same as (2) but including a reformulation with higher intake of protein foods and physical activity intervention. Each strategy is followed until the end of follow-up. Participants assigned to a lifestyle strategy are expected to maintain their dietary intake or amount of physical activity at or above the pre-specified threshold by the corresponding intervention strategy as detailed in Table S1 and reference (19). The dietary intakes of participants are measured using 24-h dietary recalls, and physical activity using the PASE questionnaire at each follow-up to ensure adherence to the intervention.	Same. However, we assumed: • that each dietary assessment period (ie, within 2 months beginning at each follow-up) accurately reflects the average diet in the interval between follow-ups; • that random measurement error in dietary intakes assessed by the mean of three 24-h dietary recalls at each follow-up have a negligible impact on the effect estimates; • that physical activity during the 7 days assessed by the PASE questionnaire reflects the average physical activity in the interval between follow-ups.
Assignment	Participants are randomly assigned to a dietary strategy but are not blinded to their assignment.	We attempted to emulate randomized assignment by statistically adjusting for dietary intakes before baseline and baseline covariates. We assumed no unmeasured or residual confounding after adjusting.

[a]Abbreviations: FFQ, food-frequency questionnaire; NuAge, Quebec Longitudinal Study on Nutrition and Successful Aging; PASE, Physical Activity Scale for the Elderly.
[b]See "Hypothetical intervention" for detailed intervention.

to those higher protein requirements among older adults from Canada (12). For example, more than 18% and 50% of Canadians aged 65 years or older would have protein intakes below the current recommended daily allowance of 0.8 g/kg and the higher recommended intake of 1.0 g/kg, respectively, (12). Thus, the universal CFG recommendations may not be optimal for older adults. Finally, only 33% of older adults in Canada meet moderate-to-vigorous physical activity recommendations (14). Given the benefits of physical activity and protein intake to improve muscle function and strength (13, 15), how the adherence to CFG recommendations alone or combined with physical activity contributes to favorable health outcomes should be examined.

A large randomized controlled trial (RCT) would ideally document the effect of adhering to CFG recommendations. However, nutritional intervention studies are particularly challenging to conduct due to blinding and long-term adherence issues (16, 17). Indeed, strictly controlling dietary intakes over a long period is challenging in free-living conditions. As a first step, using observational data is an appropriate alternative. Using the target trial framework (18–20), our objective was to estimate the difference in key health outcomes among eligible community-dwelling older adults from the NuAge study, at the end of follow-up, had they followed the intervention vs., instead, had they maintained their diet and physical activity habits. More precisely, we aimed to estimate the end of follow-up difference in muscle strength, physical function as well as cardiometabolic markers and cognition following these hypothetical interventions over 3 years, compared with no intervention: (1) the effect of adhering to CFG 2019 recommendations (CFG); (2) same as 1, with additional protein foods (CFG-PRO); (3) increasing physical activity without diet modifications (PA); and (4) same as 1, with additional protein foods and increasing physical activity (CFG-PLUS). Of note, "no intervention" corresponds to the habitual diet and physical activity habits as reported by participants. We hypothesized that adherence to CFG recommendations would improve cardiometabolic and cognitive health but that only the enhanced recommendations, ie, those including additional protein foods and physical activity would improve muscle strength and function compared with no intervention.

Methods

Design and participants

Complete details about the present study protocol have been published elsewhere (19), including the justification for the hypothetical diet and physical activity intervention, the hypothesized relationships between variables and the thorough description of the target trial. Figure S1 presents an overview of the study design. Briefly, participants were adults aged 67-84 years from the longitudinal NuAge Database and Biobank (21, 22). The NuAge participants were identified in 2003 based on a random sample of 36,183 males and females from the Quebec health insurance database, stratified for age and sex (21). A total of 1793 participants were recruited from three regions in the Province of Quebec, Canada (Sherbrooke, Montreal, or Laval) between

Table 2 Emulation of a lifestyle intervention target trial using non-experimental data from the NuAge study: outcomes, follow-up, contrast and analysis[a].

Trial Component	Target Trial Specification	Target Trial Emulation Using NuAge Data
Outcomes	• Muscle function (4-m walking speed, timed up & go); • Muscle strength (handgrip, elbow flexor and quadriceps strength); • cardiometabolic health markers (waist circumference, systolic blood pressure, diastolic blood pressure, glomerular filtration rate, glucose), and cognition (3MS score). The post-intervention difference in 4-m walking speed is the primary outcome.	Same. However, no primary outcome was identified. The main purpose of the emulation is not to detect an effect, but rather to estimate effect.
Time zero and follow-up	The study starts at baseline and ends at incomplete follow-up or 3 years after baseline, whichever occurs first. Participants meet with the research staff at their annual follow-up (3 in total after baseline).	Same. An incomplete follow-up was defined as missing data for questionnaires on two consecutive follow-ups (non-response), loss to follow-up or missing outcome data at the end of follow-up.
Causal contrast	• Per-protocol effect • Intention-to-treat effect	Observational analog of the: • per-protocol effect: primary analysis • Intention-to-treat effect: sensitivity analysis only. The observational analog of the intention-to-treat contrast corresponds to the baseline values of the intervention, which are "assigned" and initiated at the same time. Time-varying covariate, diet, and physical activity data are not considered for this contrast.
Statistical analysis	• Per-protocol analysis: apply the parametric g-formula algorithm to compare post-intervention outcomes between groups receiving each treatment strategy with adjustment for pre- and post-baseline factors associated with adherence to intervention strategies and incomplete follow-up. • Intention-to-treat analysis: apply inverse probability weighting with adjustment for pre- and baseline factors associated with incomplete follow-up to account for study dropouts..	• Same for the per protocol analysis (primary analysis). • Same for the intention-to-treat analysis (sensitivity analysis). However, the observational analog of both analyses required additional adjustment for confounding at baseline and before baseline due to previous dietary habits. We assumed that statistical models were correctly specified (eg, modeling of outcomes and covariates data).

[a] Abbreviations: 3MS, modified Mini-Mental State Examination; NuAge, Quebec Longitudinal Study on Nutrition and Successful Aging.

2003 and 2005 at baseline and followed over three years. Data collection was completed in June 2008. All participants of the NuAge study provided informed consents. A subset of 1753 participants (98%) further agreed to have their data included in the NuAge Database and Biobank used in the present study (21).

We aimed to explicitly emulate the protocol of a target trial (18, 20, 23) using non-experimental data from the NuAge study (Tables 1 and 2).

Exposure: diet and physical activity

24-hour dietary recalls (main exposure)

Dietary intakes at baseline and at each annual follow-up (up to three) were assessed using interviewer-administered 24-h dietary recalls (22). Up to three non-consecutive 24-h dietary recalls were collected at each time, including one face-to-face interview during the annual assessment and two unannounced interviews by telephone within two months. The interviews were administered according to the United States Department of Agriculture multiple-pass method (24). Portion size estimation was facilitated using portion-size models and pictures of standardized food portions. For the present study, reported food and beverages were classified according to the food categories corresponding to each component of the hypothetical diet intervention (complete detail in Supplemental Methods—Hypothetical intervention). The categories were vegetables and fruits, whole-grain foods, plant-based protein foods, animal-based protein foods, unsweetened milk and plant-based beverages with protein, unsaturated fats and oils, water, and other healthy beverages. Foods and beverages not recommended were also classified including other low nutritive value foods, sugary drinks and alcohol, and non-whole grain foods (19). The number of reference amount (RA) was calculated for each dietary item. Similar to a standardized portion size, RA corresponds to the amount of food in grams typically consumed at one sitting in Canada (25). Mean intakes in RA were then calculated at each follow-up for each category and participant based on all 24-h dietary recalls completed with 500 kcal or more (19).

Food frequency questionnaire (pre-baseline dietary intakes)

Dietary intake in the year prior to the baseline were assessed using a semi-quantitative food frequency questionnaire (FFQ) (26). Portion size estimation was facilitated using pictures of sample servings throughout the questionnaire. To have standardized portion size similar to the 24-h dietary recall data, intake data for each question were converted to RA per day. Then, the sum of intakes was calculated among the food and beverage categories of the hypothetical intervention. FFQ with reported energy intakes <800 kcal and >4200 kcal (males) or <500 and >3500 kcal (females) were excluded as well as FFQ with >25% missing responses.

Physical activity

Physical activity over the past 7 days was estimated using the Physical Activity Scale for the Elderly (PASE) questionnaire (27, 28). The questionnaire was completed at the same assessment visit as the first 24-h dietary recall at each yearly follow-up. The amount of light intensity or higher physical activity in minutes per day was derived based on individual PASE questions.

Hypothetical intervention

Covariates

Sociodemographic, lifestyle, health, and anthropometric data were collected using interviewer-administered standardized questionnaires and procedures at baseline and at each follow-up (21, 22). Potential data-entry errors were mitigated using predefined fields and outlier flags. Trained registered dietitians and nurses conducted the interviews (22).

Covariates were selected based on background knowledge and causal directed acyclic graph to account for confounding due to prior dietary habits (before baseline), individual factors, the propensity towards health-seeking behaviors, and disease burden (19). The pre-baseline covariates were intakes (RA/day) of vegetables and fruits, whole grains, refined grains, animal-based protein foods, plant-based protein foods, milk, sugary drinks and alcohol, and other low nutritive value foods, oils and fats that are saturated or unsaturated. The baseline covariates were age (years), sex (male or female), region (Sherbrooke, Montreal, or Laval), education (years), height (m), and former cancer (yes/no). The time-varying covariates were intakes of unsweetened drinks (RA/day), total dietary intakes (RA/day), measured bodyweight (kg), light to high intensity physical activity (minutes/day; in diet-only interventions), living alone (yes/no), the number of medication, the use of vitamins, minerals or natural health product (yes/no), the consumption of alcohol in the prior month (yes/no), current smoking (yes/no), the presence of chronic disease (diabetes, high blood pressure or heart disease), and being "excused" from adhering to the intervention (yes/no; see below for details). Data on time-varying covariates collected at each annual follow-up were used in the analysis, as described below.

Outcomes

Key outcomes related to muscle strength, muscle function as well as cardiometabolic and cognitive health were selected based on availability in the NuAge Database and Biobank and relevance for older adults (19, 21, 22). All outcomes were measured using standardized protocols (22) (Table S2). The muscle strength outcomes were handgrip, elbow flexor, and quadriceps strength. The muscle function outcomes were walking speed and timed "Up & Go"; the cardiometabolic health outcomes were waist circumference, blood pressure (systolic, diastolic), blood glucose, estimated glomerular filtration rate (eGFR); and cognition was assessed using the modified Mini-Mental State Examination (3MS) score. Blood samples were obtained in the morning after an overnight fast. Participants were instructed not to eat or drink (except reasonable amount of water), smoke, or chew gum after 19:00 the evening before. The end of follow-up values were used as outcomes.

Statistical analyses

All analyses were conducted in R version 4.4.3 (February 28, 2025; R foundation) and the gfoRmula package v1.1.1 (32).

G-formula algorithm

The observational analog of the per protocol contrast for the hypothetical interventions, the primary analysis, was estimated using the parametric g-formula algorithm (32, 33). Briefly, the g-formula algorithm uses parametric models and Monte Carlo simulations to estimate causal effects in longitudinal data including time-varying exposures and confounders (Supplemental Methods—g formula algorithm). In the present study, the g-formula was implemented to estimate the effect of adhering to the hypothetical intervention pre-specified in Tables 1 and 2 and Table S1, while accounting for confounding and loss to follow-up. Table S3 describes the modeling approach for each variable. Variance was estimated using 1000 bootstrap samples (percentile method). The mean difference between outcomes under the hypothetical intervention and "no intervention" (natural course) estimated the effect of the intervention. To assess the added value of consuming more protein foods and including physical activity, the between-intervention differences were also estimated for CFG-PLUS compared with CFG alone.

The hypothetical lifestyle intervention could be difficult or impossible to implement for participants with a high disease burden, especially for the physical activity component (19, 34). To mitigate confounding by disease burden, participants, who received a cancer diagnosis, were hospitalized (>1 day) or were instructed to bed rest (>1 day) during the year between follow-ups were "excused" from adhering to the intervention. In other words, "excused" individuals were considered in the intervention group data to estimate outcome values, while leaving their dietary intakes or amount of physical activity unchanged.

Missing time-varying data

The previous value of missing time-varying data at a given follow-up was carried forward once. Participants were considered as having incomplete follow-up if questionnaire non-response occurred at 2 consecutive follow-ups. Table S4 presents the proportion of missing time-varying diet, physical activity, and covariates across follow-ups in eligible NuAge participants.

Subgroup and sensitivity analyses

Stratified analyses by sex were conducted to assess the impact of biological sex and, to some extent, gender.

Sensitivity analyses were conducted to challenge key assumptions of the causal effect estimation process. First, the effect of the hypothetical interventions on albumin concentrations was estimated as a negative control outcome (35). Albumin was selected as a marker of overall health that should not be strongly modified by the hypothetical intervention, but that may otherwise reflect residual or unmeasured confounding by disease severity (36). Second, the impact of within-individual random errors associated with 24-h dietary recalls was assessed by comparing the uncorrected effect estimates with corrected effect estimates using the National Cancer Institute multivariate method (19, 37) (Supplemental Methods—Sensitivity analysis to assess the impact of measurement error). Third, to assess model misspecification in the g-formula algorithm, predicted values of time-varying variables under no intervention, as estimated by the g-formula, were compared to those estimated by inverse probability weighting (38).

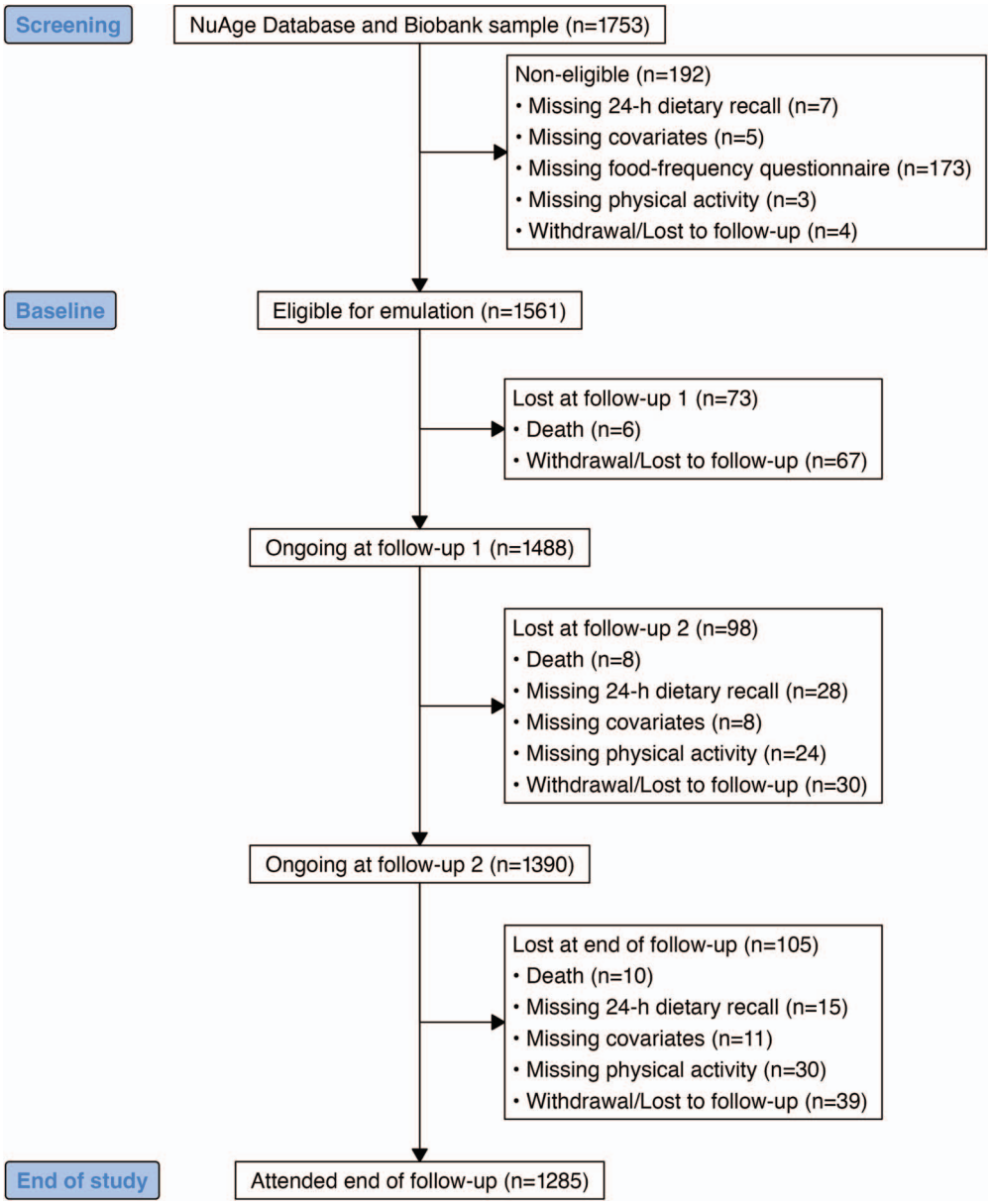

Figure 1 Flowchart of participants.

Results

Study participants

Among 1753 total NuAge participants, 1561 were eligible at baseline (Figure 1). The characteristics of eligible and excluded NuAge participants (n = 192) are shown in Table S5. Among eligible participants, 276 (17.7%) were lost during follow-up. Median (Q1, Q3) follow-up time was 3.0 years (2.9, 3.1). Table S6 presents baseline characteristics of eligible participants across adherence score to CFG. Compared with participants in the first quarter of adherence score to CFG, participants in the highest quarter included more females, had a lower body mass index, were more likely to report doing 150 minutes of physical activity per week, to report not smoking, to consume vitamin or mineral supplements, or natural health products.

Tables S7–S9 show dietary intakes across follow-ups, the proportion of participants meeting intervention targets, and dietary intakes after the hypothetical intervention, respectively. Table S10 presents the observed values of outcomes and missing data across follow-ups in eligible NuAge participants.

Effect of hypothetical interventions

The mean proportions of participants who had their reported dietary intakes or amount of physical activity modified across follow-ups were 91% for the CFG intervention, 92% for the CFG-PRO intervention, 55% for the PA intervention, and 92% for the CFG-PLUS, respectively. The observed proportion of participants which were excused from adhering to the hypothetical interventions was 12% across follow-ups.

Figures 2-4 show the difference in muscle strength, function, and cardiometabolic health outcomes, respectively, after the hypothetical interventions at the end of follow-up.

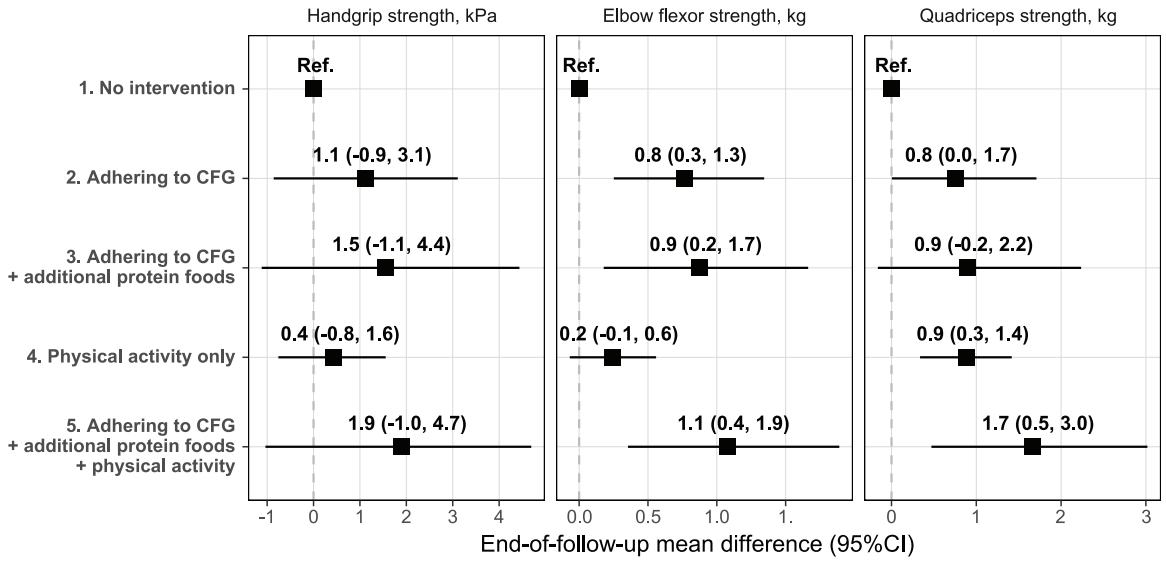

Figure 2 Mean difference in muscle strength outcomes after the 3-year hypothetical interventions, compared with no hypothetical intervention, in eligible NuAge participants. Effect estimates were obtained using the g-formula algorithm (see section Methods). Physical activity corresponds to that of light intensity or higher. Models were adjusted for the covariates age, sex, hormone replacement therapy, region, education, height, cancer prior to baseline, water and other healthy beverage intakes, total dietary intakes, physical activity (for diet-only interventions), living alone, measured body weight, number of medications, vitamin, mineral or natural health product consumption, alcohol consumption in the last month, current or former smoker, self-reported diabetes, self-reported high blood pressure, self-reported heart problems, as well as incident hospitalization, bed rest, or cancer. Abbreviation: NuAge, Quebec Longitudinal Study on Nutrition and Successful Aging.

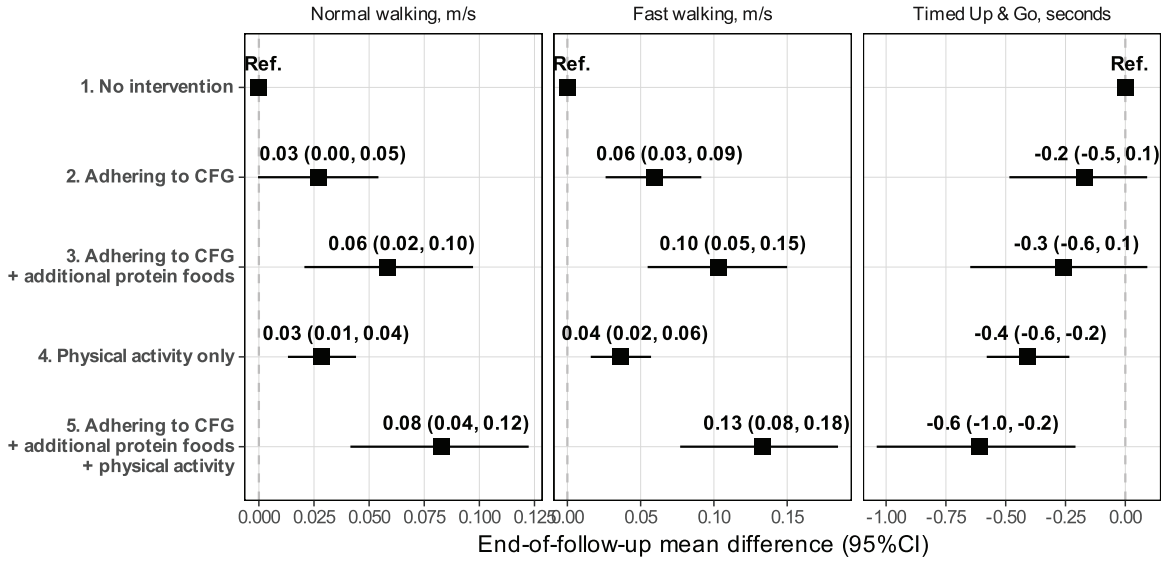

Figure 3 Mean difference in muscle function outcomes after the 3-year hypothetical interventions, compared with no hypothetical intervention, in eligible NuAge participants. Effect estimates were obtained using the g-formula algorithm (see section Methods). Physical activity corresponds to that of light intensity or higher. Models were adjusted for the covariates age, sex, hormone replacement therapy, region, education, height, cancer prior to baseline, water and other healthy beverage intakes, total dietary intakes, physical activity (for diet-only interventions), living alone, measured body weight, number of medications, vitamin, mineral or natural health product consumption, alcohol consumption in the last month, current or former smoker, self-reported diabetes, self-reported high blood pressure, self-reported heart problems, as well as incident hospitalization, bed rest, or cancer. Abbreviation: NuAge, Quebec Longitudinal Study on Nutrition and Successful Aging.

Muscle strength

Compared with no intervention, CFG would have increased elbow flexor strength by 0.8 kg (95%CI: 0.3, 1.3) and quadriceps strength by 0.8 kg (95%CI: 0.0, 1.7). The addition of protein foods did not change these differences. Independently of diet, the PA intervention would have improved elbow flexor by +0.2 kg (95%CI: −0.1, 0.6) and quadriceps strength by +0.9 kg (95%CI: 0.3, 1.4). Thus, adherence to CFG-PLUS resulted in the largest elbow flexor and quadriceps strength increase compared with no intervention (+1.1 kg [95%CI: 0.4, 1.9] and + 1.7 kg [95%CI: 0.5, 3.0], respectively). No differences were observed for handgrip strength.

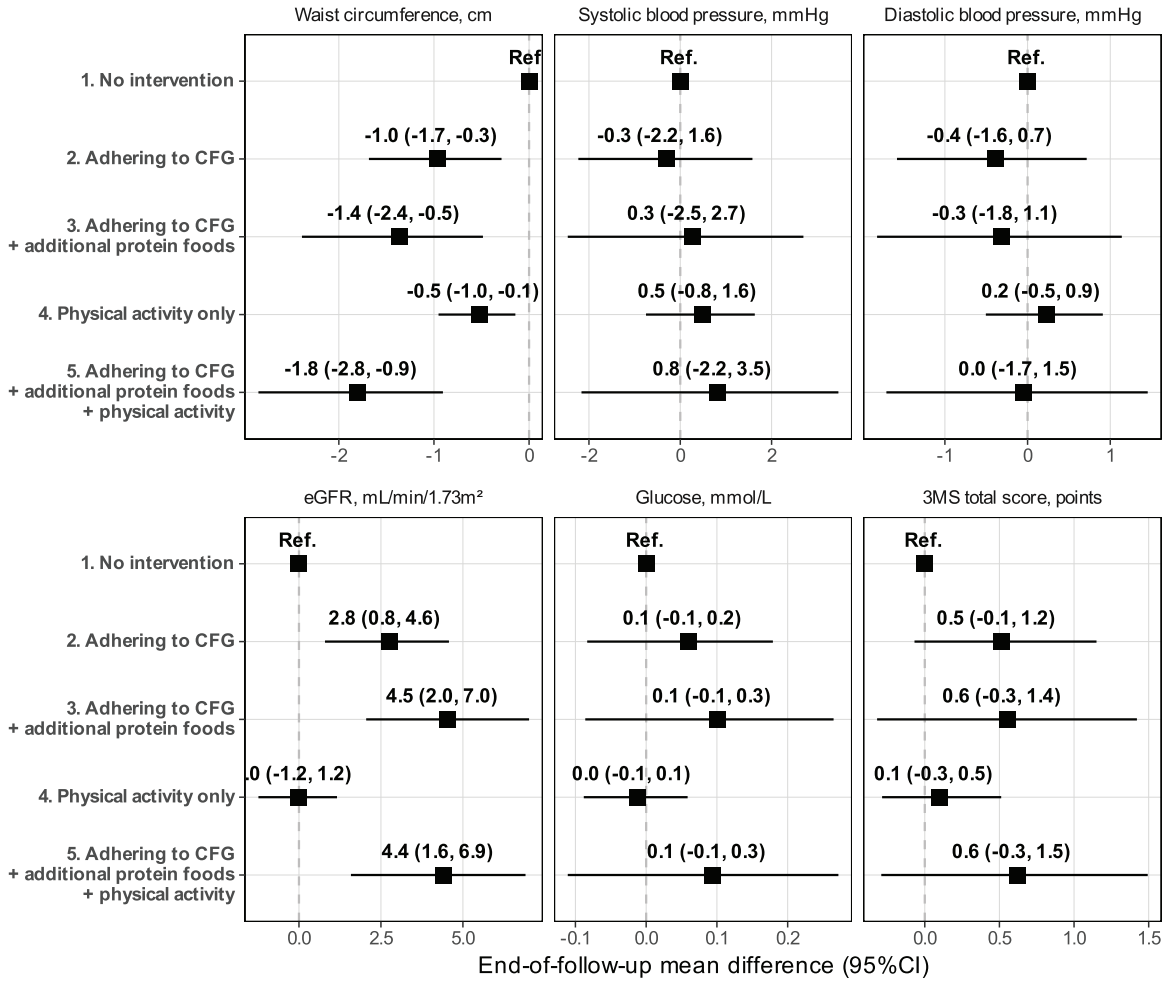

Figure 4 Mean difference in cardiometabolic health and cognition outcomes after the 3-year hypothetical interventions, compared with no hypothetical intervention, in eligible NuAge participants. Effect estimates were obtained using the g-formula algorithm (see section Methods). Physical activity corresponds to that of light intensity or higher. Models were adjusted for the covariates age, sex, hormone replacement therapy, region, education, height, cancer prior to baseline, water and other healthy beverage intakes, total dietary intakes, physical activity (for diet-only interventions), living alone, measured body weight, number of medications, vitamin, mineral or natural health product consumption, alcohol consumption in the last month, current or former smoker, self-reported diabetes, self-reported high blood pressure, self-reported heart problems, as well as incident hospitalization, bed rest, or cancer. Abbreviation: NuAge, Quebec Longitudinal Study on Nutrition and Successful Aging.

Muscle function

All hypothetical interventions would have increased normal and fast walking speed compared with no intervention, but only the inclusion of physical activity improved the Timed Up & Go performance. The Timed Up & Go performance was 0.4 s faster (95%CI: −0.6, −0.2) in the PA intervention compared with no intervention. This effect was slightly greater in CFG-PLUS (−0.6 m/s; 95%CI: −1.0, −0.2) compared with no intervention. Similarly, the adherence to the CFG-PLUS intervention would have produced the highest increase in normal walking speed (+0.08 m/s; 95%CI: 0.04, 0.12) and fast walking speed (+0.13 m/s; 95%CI: 0.08, 0.18). More precisely, the increase in normal and fast walking speed were 0.06 m/s (95%CI: 0.03, 0.08) and 0.07 m/s (95%CI: 0.04, 0.11), respectively, greater in the CFG-PLUS intervention with additional protein foods and physical activity compared with the CFG intervention only.

Cardiometabolic health and cognition

Compared with no intervention, all hypothetical interventions reduced waist circumference. The largest reduction was observed for CFG-PLUS (−1.8 cm; 95%CI: −2.8, −0.9). The eGFR rate was increased after the hypothetical interventions, except for the PA intervention. The largest increase was observed for CFG-PRO (+4.5 mL/min/1.73m^2; 95%CI: 2.0, 7.0). The CFG intervention was compatible with a small increase for the 3MS total score compared with no intervention (+0.5 points; 95%CI: −0.1, 1.2).

Sex-stratified analyses

Effect estimates were mostly consistent in their direction but slightly varied in magnitude and precision between males and females (Figure S2-Figure S4). For example, compared with no intervention,

CFG would have increased leg strength by 1.7 kg (95%CI: 0.0, 3.1) in males and 0.4 kg (95%CI: −0.5, 1.5) in females. The estimated effects on eGFR across hypothetical diet interventions was only observed in males (Figure S4).

Sensitivity analyses

Assessment of unmeasured confounding

The 95%CI from the negative control analysis were compatible with both very small decrease and very small increase in albumin concentration, including the null value (Table S11). For example, the adherence to CFG-PLUS was estimated to increase albumin concentration by 0.1 g/L (95%CI −0.4, 0.7) compared with no intervention (Table S11).

Assessment of the impact of measurement error

For most outcomes, the biases due to random errors were mostly small on the absolute scale and showed an underestimation of effects (Table S12). The biases did not modify the direction of effect estimates. The comparison between the error-prone and corrected estimates showed that effects were underestimated by 0.5-fold for quadriceps strength (strength outcomes); underestimated by 0.4-fold for Timed Up & Go and underestimated by 0.8-fold for normal walking (function outcomes); underestimated by 0.3-fold for 3MS total score, and underestimated by 0.5-fold for waist circumference (cardiometabolic health and cognition outcomes).

Assessment of model misspecification

The g-formula predicted values for time-varying diet, physical activity, and covariates were generally consistent with observed values (Figure S5).

Discussion

In this study, we used a target trial emulation to estimate the effects of adhering to CFG recommendations on muscle, cardiometabolic health, and cognition in adults aged 67 years and older. We also investigated the value of adding protein foods in combination with physical activity of light intensity or higher in addition to adhering to CFG recommendations. Compared with no hypothetical intervention, we found that adhering to CFG recommendations would have slightly improved arm and leg strength, walking speed, cognitive health score, reduced waist circumference, and increased eGFR. The addition of more protein foods and physical activity would have further improved walking speed compared with adherence to CFG recommendations only.

To our knowledge, this study is the first to estimate the impact of adhering to CFG recommendations on muscle function, strength, cardiometabolic health, and cognition of older adults. Of note, the hypothetical intervention of adhering to CFG increased protein food intake and overall diet quality (eg, vegetables and fruits, whole-grain foods) compared with no intervention in this sample. We emphasize that results reflect differences compared with the absence of change in dietary intakes or the amount of physical activity. In other words, effect estimates are not absolute improvements over time but reflect 3-year decline attenuations. For example, we found an end of follow-up increase of 1.7 kg in quadriceps strength in CFG-PLUS compared with no intervention. Accordingly, the observed absolute 3-year change of −2.4 kg under no intervention, corresponding to an annual −3.0% loss, as reported by others (39), would be approximately −0.7 kg under CFG-PLUS (0.9% loss per year) (Table S10). The 1.7-kg-improvement would thus attenuate the observed 3-year decline in leg strength, which is a favorable outcome in older adults (39, 40).

To date, no previous RCT have examined the effect of adhering to CFG recommendations per se, alone or in combination with physical activity in older adults. Previous RCT have assessed the effect of various diet intervention, exercise or both on physical frailty, and muscle strength or function (41–43). Among nutritional interventions, the effect of protein supplementation, with or without resistance exercise, on muscle strength has been investigated in numerous RCT (44–46).

Over a 2-year follow-up, Teh et al. assessed the effectiveness of a group-based cooking skills and motivation intervention coupled with a strength and balance exercise program on frailty among prefrail older adults (41). Short-term improvements were found in the combined intervention group, but no meaningful differences in frailty scores persisted at the end of follow-up. Hsieh et al. reported improvements in frailty score, walking speed, and leg strength after a 6-month home-based nutrition and exercise interventions, alone or in combination, in older adults (42). Of relevance, the combination of nutrition and exercise intervention yielded the largest difference for walking speed and leg strength compared with both interventions separately (42). In a 4-month RCT, older women experienced 18% greater leg strength gains after resistance exercise when they were provided with 160 g of cooked lean red meat compared with pasta or rice only (43). Overall, the observation that the inclusion of an exercise or physical activity intervention on top of dietary changes yields the largest gain for walking speed (42) or leg strength (42, 43) is consistent with our findings. The finding of improved strength after increasing the intake of protein is not unanimous. For example, in a meta-analysis of 8 interventions (44), the addition of protein supplements in combination with resistance exercise did not clearly improve leg strength of older adults compared with resistance exercise only (mean difference: +1.4 kg; 95%CI, −1.0 to 3.8). These mixed findings are possibly related to the intervention format (eg, group vs. individual counseling), intensity, adherence, follow-up duration, and population characteristics. Similarly, considering the quality and bioavailability of protein among different protein foods may also be relevant to optimize muscle strength and function in older adults.

The increase in walking speed compared with no intervention is a noteworthy finding with regard to overall health. Previous literature showed that small meaningful changes in gait speed correspond to a difference of at least 0.03 to 0.05 m/s (47), while a difference up to 0.1 m/s corresponds to substantial improvements (48). A difference of 0.1 m/s in gait speed was also associated with a 12% lower risk of death in a pooled analysis of more than 34,000 community-dwelling older adults aged 65 years or older (49). In the present study, the combination of CFG adherence, additional protein and physical activity yielded gait speed effect estimates (+0.08 m/s; 95%CI: 0.04, 0.12) compatible with substantial improvements and reduced mortality risk. These estimated differences should be interpreted while acknowledging that older adults with walking speed above 1.0 m/s have a low probability of short-term self-reported mobility disability (50), as in the present study (Table S10). Finally, the finding of reduced waist circumference in all hypothetical interventions is also consistent with the reduced 10-y cardiovascular disease risk associated with adherence to CFG recommendations (10).

Strengths of this study include the emulation of a target trial to avoid many fundamental biases of causal effect estimation using non-experimental data, the comprehensive diet and covariate data collection, the ability to examine multiple hypothetical interventions

and the sensitivity analyses to assess robustness of findings. Emulating a target trial enabled the analysis of incident rather than prevalent dietary changes, explicit modeling of time-varying intakes (per-protocol contrast), and estimation of sustained intervention effects in all participants rather than extreme group comparisons. Limitations must be highlighted. First, while the 24-h dietary recall is one of the most accurate self-report dietary assessment method, dietary intakes are known to be affected by systematic errors or bias (51, 52) which, in turn, could bias effect estimates unpredictably. Of note, systematic errors contribute less to total error on 24-h dietary recall contrary to other common instruments such as the food frequency questionnaire. Second, most participants had reported dietary intakes and amount of physical activity that did not meet the a priori intervention targets (Table S8). Consequently, the effect estimates may be based on a small subset of participants with distinct characteristics, challenging the positivity assumption of causal effect estimation. Third, the NuAge sample size is relatively small and homogenous. Participants are predominantly Caucasians, and the estimated effects may not be generalizable to more diverse populations. Lastly, though sensitivity analyses did not reveal major issues, it does not imply that all assumptions are correct. Our findings hinge on strong assumptions including the lack of unmeasured and residual confounding, which is never guaranteed with observational data.

In conclusion, adhering to CFG 2019 recommendations, compared with no hypothetical intervention, would have improved arm and leg strength as well as walking speed of adults aged 67 years or older over a 3-year follow-up. Increasing the amount of physical activity and the intake protein foods would have yielded clinically relevant improvements in walking speed compared with CFG alone and no intervention. Our findings support the paradigm of increasing the intake of protein foods and the amount of physical activity in older adults, which should be considered in future studies and dietary guidelines. We stress that these results depend on the assumptions of no unmeasured confounding, no measurement error and correct statistical models. Accordingly, randomized trials are required to minimize these limitations and confirm our results. The target trial described in this study may serve as a starting point for the design of future studies.

Data and code availability

The data underlying this article cannot be shared publicly due to the privacy of individuals who participated in the study. Eligible researchers can request access to de-identified data from the NuAge Database and Biobank at https://nuage.recherche.usherbrooke.ca/en/demande-dacces/. Final data for the present study were obtained on November 16, 2023. Analysis code will be made available at https://github.com/didierbrassard/NuAge_TargetTrial_CFG

Posthumous authorship

Sadly, Nancy Presse passed away in February 2025 during the finalization of this manuscript. We wish to acknowledge her contribution to the present work and to the nutrition and aging research field, in a dedicated career that ended too soon.

Author contributions

Didier Brassard (Conceptualization [lead], Data curation [lead], Formal analysis [lead], Funding acquisition [equal], Methodology [lead], Visualization [lead], Writing—original draft [lead]), Nancy Presse (Conceptualization [supporting], Project administration [supporting], Supervision [supporting], Writing—review & editing [supporting]), Stéphanie Chevalier (Conceptualization [supporting], Funding acquisition [equal], Project administration [supporting], Supervision [lead], Writing—review & editing [lead])

Supplementary material

Supplementary material is available at *AJE Advances: Research in Epidemiology* online.

Conflicts of interest

None declared.

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Ethical approval

The NuAge study protocol was approved by the Research Ethics Boards of the Institut universitaire de gériatrie de Montréal and the Institut universitaire de gériatrie de Sherbrooke (Quebec, Canada). The NuAge Database and Biobank have been approved by the Research Ethic Board of the CIUSSS de l'Estrie-CHUS (Quebec, Canada). Ethic approval for secondary analyses of the NuAge Database and Biobank was also obtained from the McGill University Research Ethics Board Office (#22-11-041).

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