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Challenges in Designing and Delivering Diets and Assessing Adherence: A Randomized Controlled Trial Evaluating the 2010 Dietary Guidelines for Americans

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ABSTRACT

Background: Controlled-feeding trials are challenging to design and administer in a free-living setting. There is a need to share methods and best practices for diet design, delivery, and standard adherence metrics.

Objectives: This report describes menu planning, implementing, and monitoring of controlled diets for an 8-wk free-living trial comparing a diet pattern based on the Dietary Guidelines for Americans (DGA) and a more typical American diet (TAD) pattern based on NHANES 2009–2010. The objectives were to 1) provide meals that were acceptable, portable, and simple to assemble at home; 2) blind the intervention diets to the greatest extent possible; and 3) use tools measuring adherence to determine the success of the planned and implemented menu.

Methods: Menus were blinded by placing similar dishes on the 2 intervention diets but changing recipes. Adherence was monitored using daily food checklists, a real-time dashboard of scores from daily checklists, weigh-backs of containers returned, and 24-h urinary nitrogen recoveries. Proximate analyses of diet composites were used to compare the macronutrient composition of the composite and planned menu.

Results: Meeting nutrient intake recommendations while scaling menus for individual energy intake amounts and food portions was most challenging for vitamins D and E, the sodium-to-potassium ratio, dietary fiber, and fatty acid composition. Dietary adherence for provided foods was >95%, with no differences between groups. Urinary nitrogen recoveries were ~80% relative to nitrogen intake and not different between groups. Composite proximate analysis matched the plan for dietary fat, protein, and carbohydrates. Dietary fiber was ~2.5 g higher in the TAD composite compared with the planned menu, but ~7.4 g lower than the DGA composite.

Conclusions: Both DGA and TAD diets were acceptable to most participants. This conclusion was supported by self-reported consumption, quantitative weigh-backs of provided food, and urinary nitrogen recovery. Dietary adherence measures in controlled-feeding trials would benefit from standard protocols to promote uniformity across studies. The trial is registered at clinicaltrials.gov as NCT02298725. *Curr Dev Nutr* 2020;4:nzaa022.

Keywords: controlled feeding, free-living trial, dietary adherence, diet patterns, diet acceptability, menu design, blinding diet interventions

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Supplemental Tables 1–8 and Supplemental Figure 1 are available from the “Supplementary data” link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/cdn/>.

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Abbreviations used: DAQ, Diet Acceptability Questionnaire; DASH, Dietary Approaches to Stop Hypertension; DGA, Dietary Guidelines for Americans; DGAC, Dietary Guidelines Advisory Committee; DGAR, Dietary Guidelines Advisory Report; NDSR, Nutrient Data System for Research; OMA, Official Methods of Analysis; RCT, randomized controlled trial; SoFAS, solid fats and added sugars; TAD, typical American diet; WVEIA, What We Eat in America.

Introduction

The Dietary Guidelines for Americans (DGA) are meant to be used by professionals—policymakers, dietitians and nutritionists, health care providers, school foodservice managers—and the lay public to “help people attain and maintain a healthy weight, reduce their risk of chronic disease, and promote overall health” (1). One of the goals of the DGA is to translate nutrition research into food-based recommendations, fol-

lowed by translating the recommendations into amounts and types of foods to consume. A new edition has been published every 5 y since its inception in 1980. A critique of the process for developing the DGA is that the guidelines are difficult to formulate due to the large variability in the population with regard to dietary intake and health outcomes, and consequently reducing the effectiveness of the guidelines (2). Furthermore, the DGA, as a whole-diet pattern, have rarely been tested rigorously using a randomized controlled trial (RCT) design with controlled

food intake. RCTs can establish causality (3). Hence, there is a need for well-designed and implemented RCTs to evaluate the health effects of recommended dietary patterns outlined in the DGA (4), including variations of the Mediterranean and vegetarian diet patterns.

Since RCTs have questionable long-term adherence and external validity of outcomes from the sample tested to the general population, thoughtful design is paramount. Agriculture and Agri-Food Canada released a report on Best Practices for Food-Based Clinical Trials (5), emphasizing that RCTs are the “gold standard” of clinical trials, and further stress that choosing optimal design, implementation, and reporting methods is critical. Most et al. (6) also outlined various training resources for controlled-feeding trials that are relevant while planning and conducting RCTs with controlled-feeding interventions.

Dietary adherence is yet another essential aspect of a controlled-feeding study, especially in those involving free-living participants. In controlled-feeding studies, the expectation is that participants consume only the foods and beverages that have been prepared and packaged for them by the study staff (6). However, participants may face a number of challenges when partaking in a controlled-feeding study. These include the following: sweet/salty cravings, poor social support, low levels of perceived benefit, allergies, attending special occasions, lack of motivation to change, and abstaining from certain habits such as consuming caffeine or alcohol (7). Moreira et al. (8) suggested that the removal of individual choice in controlled-feeding studies and temptations in daily life may challenge a participant's adherence. Study length, number of days in the menu cycle, and diet composition are other factors that may affect participant adherence. However, Hall and Most (9) found that neither the length of a study (between 6 and 24 wk) nor the number of repeated days in a menu cycle affected adherence.

Only 2 RCTs have been conducted to evaluate the DGA with fully controlled feeding interventions in a free-living setting, providing all foods and beverages to meet energy and nutritional requirements in the short or medium term. First, Schroeder et al. (10) tested a 4-wk DGA diet compared with a diet based on a Korean-style diet and a typical American diet [TAD; based on the NHANES dietary component, What We Eat in America (WWEIA)] in a crossover design. The study included 31 overweight and obese men and women with hypercholesterolemia as participants. Second, we (11) reported an 8-wk parallel-arm RCT comparing a 2010 DGA diet pattern with a TAD pattern (also based on the 2009–2010 NHANES WWEIA) in 52 women at risk of metabolic disease. The primary aim of the current report is to present our approach to designing the research study diet, implementing food-production approaches to blind the diet pattern, and monitoring adherence to an RCT. Data on participant adherence and acceptance of the diets are included. The approaches described herein provide a useful toolset and set of templates for future RCTs that test dietary patterns and health outcomes.

Methods

Menu development: rationale

A core study menu was created such that it could be aligned to either the DGA or the TAD. It was developed based on age- and sex-matched mean amounts consumed by individuals reported in the WWEIA survey of the 2009–2010 NHANES (11). The primary study was a randomized clinical trial focused on evaluating the effect of these 2 diets

(DGA or TAD) in 52 overweight/obese women between the ages of 20–65 y, with dyslipidemia, impaired glycemia, or both, and thus at elevated risk of chronic cardiometabolic diseases. The trial is registered at clinicaltrials.gov (NCT02298725) and our primary findings have been published earlier (11). All study protocols were approved by the Institutional Review Board of University of California, Davis, and all participants signed informed-consent forms.

Most diet intervention studies focus on either isolated nutrients, a select combination of nutrients, or isolated foods. It is not uncommon for these types of studies to use amounts that may be effective but not necessarily efficacious, because the doses delivered do not represent realistic amounts of foods or nutrients that are regularly consumed outside of the study. In contrast, the diets in this study emphasized food patterns. According to WWEIA from NHANES, adult Americans eat foods that are classified into the following food-group categories: milk and dairy; proteins; mixed dishes; grains; snacks and sweets; fruits; vegetables; beverages, nonalcoholic; alcoholic beverages; fats and oils; condiments and sauces; and sugars (12). The food-group categories outlined in the USDA Food Patterns include fruits, vegetables, grains, proteins, dairy, oils, and solid fats and added sugars (SoFAS). Hence, the primary difference between the 2 diet patterns is the relative proportions of the respective food groups. For example, Americans consume fruits such as apples, bananas, grapes, peaches and nectarines, berries, citrus fruits, melons, dried fruits, and other fruits and fruits salads; however, they fall short in meeting the recommended servings of fruits. Similarly, Americans consume milk, cheese, and yogurt, but they fall short in meeting the recommended servings of dairy. In other words, Americans are already eating many of the recommended food types but not in the recommended proportions. To illustrate the alignment of the core menu with either the DGA or TAD, both menus included a “pasta with meat sauce” dish that included spaghetti noodles, tomato-based sauce, ground beef, and mozzarella cheese. On the TAD-based menu, the ready-to-eat marinara sauce was used “as is,” whereas on the DGA-based menu, one-third of the marinara sauce was replaced with a ready-to-eat, lower-sodium tomato-basil soup. Roasted mushrooms and puréed canned white anchovies were also added to the DGA-based dish. These substitutions reduced sodium and added sugars, while increasing potassium, vegetables, omega-3 fatty acids, and “free” glutamates for taste. There was a total of 78 recipes used in the study (40% TAD and 60% in the DGA), and 16 of those (34%) recipes had shared ingredients that were modified to fit the DGA and TAD separately. These modifications helped in blinding the study menu to participants. This aspect of the menu design is discussed in detail later.

Menu development: identifying foods

In an attempt to replicate a realistic market supply, the study menu included a combination of fresh, frozen, ready-to-eat, canned, dried, cured, and manufactured foods, with >90% representing foods produced in California. A nationwide vendor (Sysco, Houston, TX) was designated for procuring shelf-stable foods. A local grocery store (Safe-way; headquarters, Pleasanton, CA) was used for fresh produce and specialty food items that were used in relatively small quantities. Other specialty foods were identified and procured through additional vendors as needed. Some commercially available foods used in this study were lower in added sugars, sodium, and saturated fat to better adhere to the dietary guidelines and used in the DGA diet. In order to maintain con-

sistency and reduce variability, foods were selected that could be reliably procured for the duration of the study. In addition to fresh, frozen, dried, and canned foods, healthier versions of manufactured foods that were lower in sodium, saturated fat, and added sugars, and higher in potassium (Campbell Soup Company) were used in the DGA diet to assist with alignment to the core diet to meet the DGA recommendations. When a food that was included in the study was not available during the execution of the controlled feeding, an appropriate substitution was identified based on nutrient tolerance criteria extracted from the Nutrition Data System for Research (NDSR) manual; foods that were considered acceptable substitutions were within ± 85.0 kcal, ± 5.0 g protein, ± 2.5 g total fat, ± 10.0 g total carbohydrate, and ± 100.0 mg sodium for 100 g of the food. In situations where no suitable substitution was readily available, the product that was the closest match was used. In all, food substitutions were identified for 27 foods, with only 4 instances of foods outside of the accepted range (**Supplemental Table 1**).

Recipe development and sensory panels

Recipe development for feeding studies is challenging because the recipes and resulting menus must address the research question and also provide study foods that participants will eat while maintaining acceptable adherence. Each participant received the same foods in varying amounts based on individual energy needs, and participants were instructed to eat everything provided. Due to varying taste preferences, foods were carefully designed to avoid extremes (too spicy vs. not spicy enough) and find the middle ground of acceptability.

In addition to the taste qualities, foods and drinks need to maintain acceptability after being frozen, thawed, and rethermed. To ensure overall acceptability of the recipes, taste testing by women and men occurred weekly over an 18-wk period, where 350 DGA-based and TAD-based recipes were evaluated for acceptability. Invitations to participate on tasting panels were distributed widely within the Center, to ensure that all the foods were tested, and a total of 2438 evaluations were collected to decide on the menu items. Panelists sat at a table between dividers and were served the same foods in a predetermined sequence. Paper forms (**Supplemental Table 2**) were used to assess recipes for appearance, aroma, taste, texture, overall acceptability of the recipe, ability to eat the foods/drinks for 3 d in a row, and on a scale of 1 to 5; and participants were also allowed open-ended comments. The aim was to identify recipes that received a minimum average score of 4.0 for each of the qualities, and a “yes” response rate of 100% across all participants for “Ability to eat 3 days in a row.” These recipes were then considered as candidates for including in the RCT. Comments for recipes were used to fine-tune the recipe further before using in a study menu. For fish recipes, only tasters who self-identified as not liking fish were used to evaluate the recipes; this helped make the fish dishes more palatable for individuals who do not like fish.

Over the course of the 8-wk feeding period, each participant ate ~ 3500 food items presented in ~ 225 meals (breakfast, lunch, and dinner were each counted as 1 meal; the combined snacks were designed so they could be eaten either all at once or spread out over the course of the day and were also counted as 1 “meal”) (**Supplemental Table 3**). In order to produce these foods resourcefully, efficiently, and safely, shelf-stable foods were prepared in bulk and stored either at 25°C in dry storage, 4°C in refrigerated storage, or -20°C in frozen storage. Fresh produce

was processed twice per week. Ultrapasteurized milk was used due to extended shelf stability.

Calculations

Another challenge was designing an experimental diet based on the USDA Food Patterns (13). In order to reduce variation in the study diet, the menus were designed at 2200 kcal/d so that they could be proportionately scaled up (to a maximum of 3100 kcal) or down (to a minimum of 1700 kcal). However, the USDA Food Patterns document was not designed as an experimental diet; the food-grouping and nutrient distribution is not evenly distributed across the range of calorie levels. For example, the maximum recommended SoFAS at the 1800-kcal level is 9% of total kilocalories; for the 3200-kcal level, it is 19% of total kilocalories. This disproportionate food grouping in the USDA Food Patterns also presented a challenge with meeting the key recommendation for potassium and sodium, both “nutrients of concern.” As energy needs increase, the USDA Food Patterns recommends more grain products; however, grain products are also one of the major sources of sodium: yeast breads contribute 7.3% of the total diet and grain-based desserts 3.4% of sodium in the American diet (14). The recommendation for dairy, a rich source of potassium, remains constant across the 1600–3200-kcal amounts. Similarly, the recommendation for fruits does not increase in proportion relative to the increase in grains. This presents a challenge in meeting the recommendation to decrease sodium and increase potassium. By adjusting the USDA Food Patterns to a more linear, directly proportional model, the study diets could be produced in a way that was more reflective of overall “diet dosage” in relation to body weight. A graphical representation of the 2010 USDA Food Pattern distributed according to the public policy document is provided in **Figure 1** as well as our conversion of the food pattern into a linear scale for the purpose of creating the menus.

A further challenge of designing the DGA diet was meeting the requirements for 2 other nutrients, vitamin D and vitamin E, especially at the lower energy amounts. To meet the requirements, fortified foods (e.g., rice and oat cereals, yogurt) were used. Since foods rich in vitamin E are also high in energy, meeting the recommendation for vitamin E presented a challenge while also meeting the designated energy prescription.

To accomplish the proportionate scaling while also considering the complexity of producing the study meals, the menu was divided into 3 core energy ranges: 1700–2100 kcal, 2200–2600 kcal, and 2700–3100 kcal. Unit foods (also called “add-ons”) were study foods that were already on the menu and matched as closely as possible to the food group and macronutrient profile of the core menus; these were used to scale the menu up or down in 100-kcal increments. Linear programming was used to calculate these unit foods so that they matched the background diet as closely as possible (see **Supplemental Table 4**, parts A and B). Creating menus by this method enabled study food units to be used for multiple participants across varying energy intake amounts. Also, if a study participant withdrew during the study, the unused foods could be used for another participant in the same treatment group and at the same core energy intake amount. This flexibility allowed for better management of food stocks in the freezer and enabled the metabolic kitchen to fine-tune the energy prescription during the beginning stages of the feeding when participants’ weights may differ from predicted or measured values.

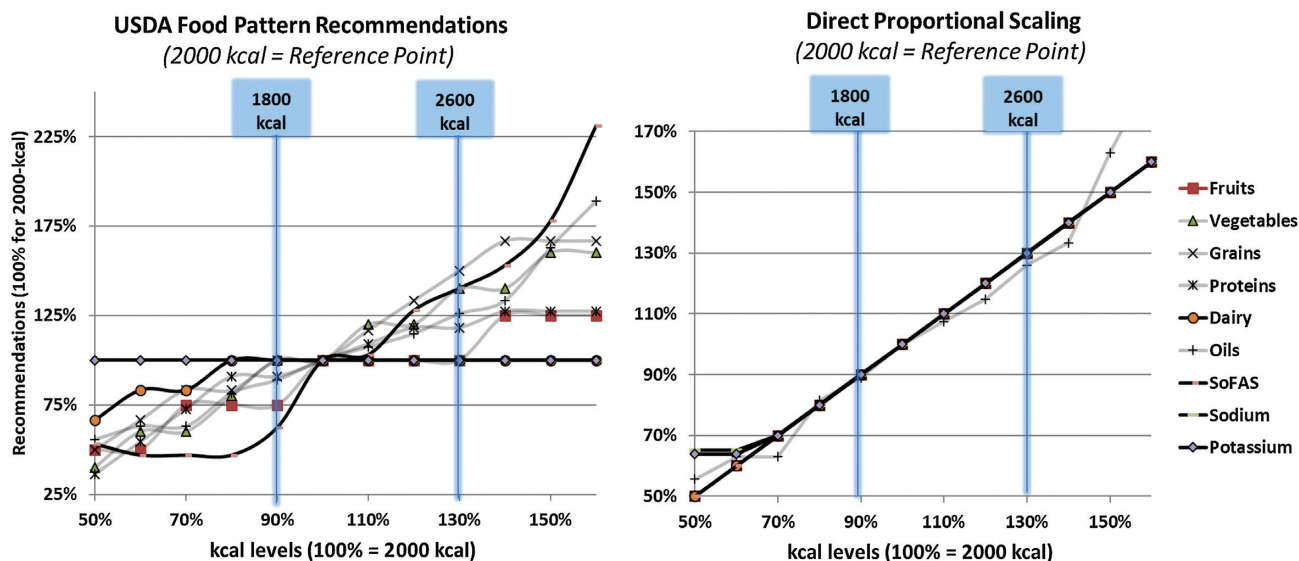


FIGURE 1 The left panel is a graphical representation of the USDA Food Patterns table (13) for the recommended food groups and their intake amounts across different calorie levels, presented as a percentage of the 2000-kcal pattern. The right panel is the proportionately scaled version of the 2000-kcal pattern used to design the DGA menu in the current study. DGA, Dietary Guidelines for Americans; SoFAS, solid fats and added sugars.

During the course of this study, only 6 individuals required an adjustment to their energy intake prescription due to a progressive increase or decrease in body weight. These changes were made in 100- or 200-kcal increments and only implemented after week 2 up until week 5, and these did not coincide with metabolic testing that occurred during baseline and weeks 2 or 8. If the prescribed energy intake amount needed changing, the incremental increase or decrease was accomplished by adding or removing 100-kcal add-on foods of balanced macronutrient composition to achieve the desired level.

Software

NDSR version 2014 was used to calculate and reconcile the nutrient and food-grouping composition of the study menu (Nutrition Data System for Research software version 2014; developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN). ProNutra (Viocare, Inc.) was used to produce the study menus. ProNutra's interface facilitates study menu development through its ability to personalize foods, nutrients, and other production components; to formulate menus to target nutrient and food group amounts using linear programming; to factor, assign, and track cycle menus at various energy intake amounts; to assign treatment codes to foods in order to facilitate double-blinding [e.g., if participants were assigned either "DRINK A" (nonfortified orange juice) or "DRINK B" (fortified orange juice), then one can enter "DRINK A" and "DRINK B" in the database used to generate production and documentation materials that all members of the study team see without revealing the true identity of the treatment because the "key" remains solely in the metabolic kitchen]; to generate inventory and bulk production needs; to generate quality-control tools; and to serve as a central location for documenting menu modifications, when needed, to accommodate some participants.

Food safety

University of California, Davis, Safety Services conducted an inspection of the production systems to assess the safety of both employees and food during the stages of production. All crew were ServSafe[®]-certified (National Restaurant Association Educational Foundation; Washington, DC). Because participants took study foods home, participants received education on the safe handling, storage, and retherming of study foods. Study foods were packed "to go" for 3 to 5 d in rolling coolers with removable hard liners (Coleman) that enabled thorough washing and sanitizing of surfaces that come into contact with food packaging. Meals were packaged in bisphenol A-free, freezer-safe, microwave-safe, and dishwasher-safe containers (Newspring Packaging). Single-use thermometers (T-Sticks; ECOLAB[®]) were provided so that participants could determine the amount of time required to retherm foods to a minimum of 74°C in their personal microwaves.

Emergency meals

In the event that a participant was unable to keep scheduled appointments, all participants received a standard emergency meal (Supplemental Table 5) that could be used instead of eating nonstudy foods. The emergency meal contained foods that were appropriate for either the DGA or TAD diet. Participants were instructed to store these meals in their freezer until needed.

Menu blinding

As mentioned earlier, the menus were designed and assembled in an attempt to blind the participants to which diet treatment they received. The strategies used included modifying recipes, replacing ingredients, puréeing foods that are widely associated with unhealthy or healthful eating patterns (e.g., hamburgers, hot dogs, fish, etc.), and layering. An example of a modified recipe is a hamburger. One

might typically expect to see a hamburger in the form of a ground beef patty sandwiched between 2 hamburger bun halves with cheese, condiments, lettuce, tomato, and onion. Instead, these components were incorporated into other recipes, such that participants received all of the foods that would make up a hamburger but not in the traditional form of a “hamburger.” In an attempt to reduce implicit bias associated with visual stimuli, some foods such as hot dogs (associated with less-healthy eating patterns) or fish (associated with more-healthy eating patterns) were puréed into recipes for both treatments. In both treatments, the hot dogs were an ingredient in a puréed chili base that was mixed with other ingredients. This way, no participant ever saw an intact hot dog even when hot dogs were on the study menu. Another attempt to reduce implicit bias associated with visual stimulus was with layering components in assembled dishes. When preparing the pizza for the TAD, for instance, foods perceived to be less healthy—beef, sausage, and cheese—were placed underneath foods perceived to be more healthy—mushrooms and tomato sauce. The pizzas on the DGA diet were assembled in the opposite fashion, with foods perceived more healthy placed beneath foods perceived to be less healthy.

Information provided to participants prior to study

During the screening process, participants were provided with a diet overview that included a list of foods, common allergens, and protein sources. This list shared the kinds of fish, meats, and other foods that were included in the study menu. Other restrictions were clearly outlined, such as the limitation of using only the coffee and tea provided by the study team, using the study-provided “cream and sugar,” and not adding flavoring agents (e.g., salt, herbs, spices, condiments, etc.) to the meals. The diet overview also provided a list of all sources of fruits, vegetables, regional and ethnic flavors, and other descriptive items to inform the participants of the study requirements. In some instances, where prospective participants asked how frequently particular foods would be on the menu, the research dietitian would provide the frequency. This provided an opportunity for prospective participants to self-select themselves out of the study.

Adherence

Currently, there is no existing “gold standard” regarding the best approach for assessing dietary adherence in controlled-feeding studies involving free-living study participants (9). The Dietary Approaches to Stop Hypertension (DASH) controlled-feeding study used several objective and subjective approaches to monitor and track adherence (15). Similar to the DASH study, adherence in this study was monitored by using biweekly body-weight measurements, consumption of 1 meal/d at the research center, weighing back unwashed food containers returned by participants, and 24-h urinary nitrogen recovery.

Participants were instructed to consume all food and beverages and return all containers unwashed including any food items that may have been uneaten. Adherence measurements relied on the honesty of the participants. Each meal included a food log (see **Supplemental Table 6**) with each of the food items listed to self-report the percentage consumed and to report any deviations. Components of the adherence tool rely on this self-report. The metabolic kitchen weighed each item that was packed out to subjects and reweighed them when

they came back as a way to validate self-reports. When either the food logs or the containers were not returned, then the adherence was determined using either the food log or containers that were returned. For example, if a participant returned the food logs but not the containers, then adherence was estimated from the food logs, whereas when a participant returned the food containers but not the food logs, then adherence was determined by weighing back the food. Adherence was scored during the weigh-back process that was used to monitor plate waste.

Further, an adherence scoring tool was created using the self-reported food log to estimate the degree of each participant’s adherence to the intervention diet. This tool was an expanded, modified form of the adherence tool used in the DASH study. The adherence tool score was based on 4 criteria: study foods not eaten, nonstudy foods eaten, coffee/tea consumed as directed, and salt/pepper/spices added. It tracked dietary adherence from the participant’s daily adherence logs by designating scores 0, 1, 2, or 3 to each area of adherence (11) (**Supplemental Table 6**). A score of “0” indicated no deviations. A score of “1” indicated that all except 1 partial serving of the foods/drinks provided were consumed. A score of “2” indicated that the participant did not consume at least 1 full serving, but no more than 2.9 full servings of study foods/drinks provided. A score of “3” indicated that the participant did not consume ≥ 3 full servings of study foods on that given day.

The dietitian compiled weekly adherence scores for enrolled participants into an “Adherence Dashboard” (**Supplemental Table 7**) for the study team to review, which showed at a glance the level of adherence of the participants. During meal pick-ups, staff members reviewed food logs to immediately catch deviations to discuss the importance of eating all and only study foods while the study was in progress. This type of monitoring allowed the staff to identify specific types of nonadherence and the degree of the deviation, which was useful for coaching the participant to improve adherence. Study coordinators repeatedly reinforced the value of honesty over perfection.

A more quantitative approach to determining overall adherence was performed at the end of the trial. All study foods and beverages provided to participants were recorded in gram weights. At the time of weigh-back, the weights of returned, unwashed food containers were recorded. The difference was assumed to be the weight of foods and beverages not eaten. Since many of the foods and beverages were incorporated into mixed dishes and recipes, no attempt was made to separate the individual components of a recipe at the time of weigh-back. The macronutrient content of the foods and beverages not consumed was estimated using food-composition data from the NDSR and reported as calories, dietary nitrogen, fat, carbohydrates, protein, and fiber. Adherence to study foods provided was thus estimated for each participant over the course of the study.

Recovery of dietary nitrogen in the urine was used as an independent, objective measure of adherence. Three times during the intervention period (week 1, week 4, and week 7) participants collected 24-h urine specimens. The total weight of the urine collected over the specified 24-h period was recorded, and aliquots of the collection were stored at -80°C until analyzed for total nitrogen and creatinine concentrations. Urinary nitrogen was determined with a nitrogen analyzer (LECO Corporation model FP628), combustion temperature of 950°C , and a proprietary LECO algorithm. Percent recovery of nitrogen provided in

TABLE 1 Composite proximate analyses report for TAD and DGA diets with comparison to the planned diet¹

Nutrients	Composites		Planned diet	
	TAD	DGA	TAD	DGA
Moisture, g/100 g	72.4	76.3	—	—
Total energy, kcal/100 g	131.0	108.0	—	—
Total energy, kJ/100 g	547.0	454.0	—	—
Energy density of diet (all foods), kcal/g	0.94	0.75	—	—
Energy density of diet (all drinks), kcal/g	0.54	0.43	—	—
Energy density (all food + all drinks), kcal/g	0.86	0.67	—	—
Protein, g/100 g	4.42	4.29	—	—
% kcal from protein	14	16	14.6	18.1
Fat, g/100 g	4.9	3.4	—	—
% kcal from fat	34	28	33.7	26.3
Total carbohydrate, g/100 g	17.3	15.2	—	—
% kcal from carbohydrates	53	56	52	55
Dietary fiber, g/100 g	1.9	1.4	—	—
Dietary fiber, ² g/1000 kcal	9.4	12.7	—	—
Dietary fiber, ³ g/2250 kcal	21.2	28.6	18.6	29.5
Added sugars, g	—	—	80.0	43.0
Sodium, mg	—	—	3912.0	2362.0
Potassium, mg	—	—	2299.0	4258.0

¹DGA, Dietary Guidelines for Americans; TAD, typical American diet.

²Based on pooled homogenate weights.

³2250 kcal represents the average planned energy intake of participants in this study.

the study diets was calculated for each participant based on the average grams of nitrogen excreted per day.

Diet acceptability questionnaire—study exit survey

The Diet Acceptability Questionnaire (DAQ; **Supplemental Figure 1**) obtained information on a participant's subjective rating of the acceptability and sensory characteristics of the provided diet. Participants were asked questions about the similarity between their habitual diet and their intervention diet as well as the likeability of the meal plan. Diet acceptability may influence how easy or difficult adherence to the intervention diets is for each participant and may indicate if baseline diet plays a role in influencing an individual's adherence to an intervention diet. During the final week of the intervention period, subjects provided feedback about the diets that they had been consuming. The questionnaire was administered to all participants with instructions to respond to the questions, using a 5-point Likert scale labeled as "strongly agree," "agree somewhat," "neither agree or disagree," "disagree somewhat," and "strongly disagree." Data from this questionnaire were used in chi-square tests to determine if there was a treatment group difference between how the participants scored the 2 interventions.

Diet composite analysis

Food and drink from each menu day were pooled and blended, by intervention diet, for each day of the 8-d cycling menu. These were then combined to represent all 8 d of the study menu. Three separate composites were prepared independently and were analyzed for both interventions in order to confirm that the diets planned using food-composition databases contained the intended macronutrient content. Composites were analyzed by Covance (Covance Laboratories). Proximate analysis for total carbohydrates (USDA Energy Value of Foods, Agriculture Handbook No. 74, pp. 2–11; 1973), total dietary fiber [AOAC Official Method of Analysis (OMA) methods: 2011.25 and 2009.01], fat (by

acid hydrolysis; AOAC OMA methods 922.06, 954.02, 933.05, 925.32), protein (by Dumas method; AOAC OMA 968.06 and 992.15), and moisture (AOAC OMA methods 925.09 and 926.08) was performed. Energy (kilocalories) was calculated from measured macronutrient data.

Statistical analyses

Chi-square tests for differences in proportion were used to evaluate differences between DGA and TAD responses to the DAQ scores. Nonparametric van der Weerden's tests were used to evaluate the outcomes of the adherence tool—Adherence Dashboard. A *P* value of 0.05 was considered significant. All statistical analyses were done on JMP Pro 14.1 (SAS Institute).

Results

Menus

The 8-d cycle menu is detailed in Supplemental Table 2, and the food and beverage sources are outlined in **Supplemental Table 8**. **Table 1** presents data obtained from diet composite analysis as well as the planned menu estimated macronutrient distribution as a comparison. Based on the proximate composite analysis results, the percentage of carbohydrates, protein, and fat very closely match what was intended and designed for the intervention. The chemical analysis in the TAD diet indicated a higher fiber content than planned (~2.5 g higher).

Diet acceptability

Participants' responses to questions that were relevant to comparing our 2 interventions were recorded and are presented in **Figure 2**. Overall diet acceptability was not significantly different between groups, partic-

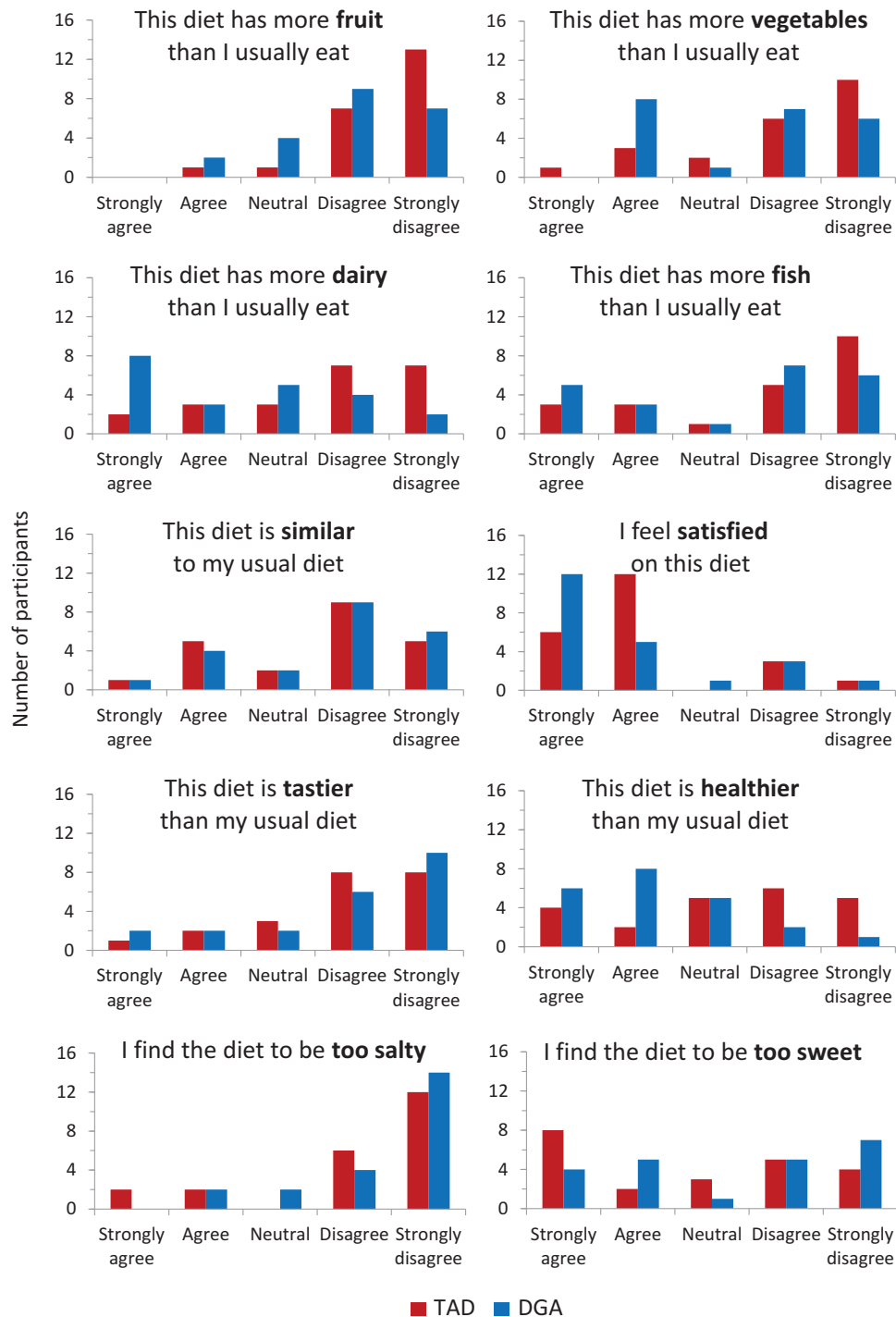


FIGURE 2 Scores from the Diet Acceptability Questionnaire for food groups for the TAD ($n = 22$) and DGA ($n = 22$) interventions in women. The pairs of bars, reading from left to right on each graph, represent the number of participants who strongly agreed, agreed, were neutral, disagreed, or strong disagreed; red bars depict the TAD group, blue bars depict the DGA group. No significant differences between the interventions were identified. DGA, Dietary Guidelines for Americans; TAD, typical American diet.

ularly with regard to perception of salty taste or in the food groups that were different between the diets (fruits, vegetables, dairy, and fish). In response to the statement “This diet is healthier than my usual diet,” the chi-square test indicated more women in the TAD group disagreed, while more women in the DGA group agreed ($P = 0.055$), but this

was not statistically significant. With regard to the acceptability of the 2 diets, 77% of the DGA group and 82% of the TAD group felt satisfied with the diets they received. However, 64% of both groups disagreed that the diet they received was tastier than their usual diets (Figure 2).

Adherence

The degree of adherence to the 2 diets, based on the adherence tool, is summarized in [Table 2](#). There were no significant differences between the 2 interventions in nonadherence, either in consuming foods, spices, or beverages consumed that were not provided or in not consuming foods that were provided. Overall, adherence deviations were primarily related to study foods. Self-reported nonstudy foods were a negligible issue throughout the intervention.

The percentage of adherence based on estimated macronutrient content of food consumed from food container weigh-back is provided in [Table 3](#). Self-reported adherence is consistently >96% for energy as well as macronutrients, with a mean of 96.5% (TAD) and 97.1% (DGA). These adherence metrics were not different between the TAD and DGA groups.

An estimated “recovery” of nitrogen in urine was calculated based on dietary nitrogen intake, using the amount of nitrogen measured in the diet composites by proximate analysis. They were not different between the 2 diets, and the recoveries were ~80% for both groups ([Figure 3](#)).

Discussion

This report summarizes our efforts in planning, designing, implementing, and monitoring adherence to a randomized controlled-feeding trial comparing a diet based on the 2010 USDA Food Patterns, which operationalize the 2010 DGA to a TAD. The menus for both diets used fresh, canned, manufactured, and frozen foods in an attempt to achieve blinding of the diets from study participants and to provide diets that could be realistically achieved by the US population. Based on adherence metrics, our approach indicated a >95% adherence (using the adherence tool as well as food weigh-backs), supported by urinary nitrogen recovery relative to dietary protein being within the literature-supported range ([16](#)). The planned diet matched composite measures of actual diet samples, with the exception of dietary fiber, where there was a minor deviation. Furthermore, per our exit survey (DAQ), participants did not perceive differences in salt taste, fruits, vegetables, dairy, or fish compared with their usual diet, nor was there a difference between the 2 diets in this respect. The only exception was a trend suggesting that the DGA group found their diet to be healthier than their usual diet, while the TAD group reported the opposite.

The DGA influence federal nutrition assistance and educational initiatives, as well as several critical health and wellness policies aimed at promoting individual and population health, such as the school food programs and consumer food labeling ([17, 18](#)). Comprehensive literature reviews that span systematic reviews, meta-analyses, and federal reports about the health effects of diets are used by the Dietary Guidelines Advisory Committee (DGAC). The DGACs, supported by federal staff, also conduct their own systematic literature reviews. These along with data from federal agencies about usual nutrient intake, eating behaviors, population characteristics, and disease prevalence are used to create the Dietary Guidelines Advisory Report (DGAR). The DGAR then informs the USDA and the Department of Health and Human Services on the final recommendations that make up the DGA policy document, and, if done well, could address several of the controversies that can arise from epidemiological analyses or observational studies that can only estab-

lish a correlation. In planning this menu, it was challenging to match nutrient requirements for vitamins D and E, the sodium-to-potassium ratio, and dietary fat composition based on food servings suggested by the USDA Food Patterns. Considering the level of difficulty faced by dietitians and professionals to plan and execute this diet, this suggests that it would be even more challenging for nonspecialists to follow these guidelines. In the future, practical implementations of the DGAs need to be tested for feasibility and ease of use.

While prospective cohort, epidemiological, and observational studies have contributed largely to our understanding of dietary patterns and their health-related outcomes, strong conclusive evidence is usually best obtained from multiple, large RCTs ([19](#)). Hence, randomized controlled-feeding trials are essential, using albeit expensive and time-consuming protocols. Successfully conducting randomized controlled-feeding trials is challenging, and the validity of observations largely depends on the robustness of study design as well as its implementation ([20](#)). Controlled-feeding studies that involve free-living participants where food is carried out of the research facility face particular challenges with achieving and tracking adherence. Providing food that the participant needs to consume does increase the probability that participants will adhere to the intervention, especially compared with a behavior change-only study design. However, the participant burden is still high, and thus prone to reduced adherence relative to an in-house study, where volunteers reside in or at least eat only at a research center. A cycling menu limits the number of foods that participants consume, increasing the probability that adherence will suffer due to tedium. Blinding is also a big hurdle, considering the obvious visual and sensory cues that accompany diets composed of disparate foods. Consistent and continuous monitoring with regular meetings with study coordinators and dietary staff can help reinforce adherence.

In the current study several approaches were used to monitor adherence. We used weigh-back of food containers as a primary measure of adherence. In addition, daily self-reported intake logs helped promote and quantify adherence in real time. Based on both of these approaches, our estimated adherence to the intervention was very high and was not different between the groups. Dietary adherence to controlled-feeding trials that involve free-living components has been reported in different ways ([8, 9, 21](#)). Most of these rely on self-reported adherence, where participants fill out records for both consuming or not consuming provided foods, as well as for consuming nonprovided foods. By leveraging multiple tools in the current study, including self-report, food weigh-back, and urine nitrogen balance, assessment of adherence was more robust than using any one single measurement and benefited from redundant measures.

In a previous DGA controlled-feeding trial comparing a 4-wk DGA diet, a Korean-style diet, and a TAD, Schroeder et al. ([10](#)) reported on details of adherence. Compliance was monitored predominantly through direct observation, by requiring participants to consume weekday breakfast and dinner onsite with study staff, while all other meals were packed out ([10](#)). Daily logs were also used to monitor study adherence. Two controlled-feeding trials using the Mediterranean-style diet both utilized similar adherence methods of requiring onsite weekday lunch meals and daily checklists ([22, 23](#)). A common method is the use of daily logs/checklists. Large-scale studies such as PREDIMED (Prevención con Dieta Mediterránea), OMNIHEART (Optimal Macronutrient Intake Trial for Heart Health), and PREMIER (Lifestyle Inter-

TABLE 2 Daily instances of nonadherence to study and nonstudy foods, coffee/tea, and salt/pepper/spice additions to the diet outside of what was provided by the study¹

	TAD	DGA	P ²
Study foods not consumed	0.70 ± 0.12	0.51 ± 0.13	0.24
Nonstudy foods consumed	0.08 ± 0.04	0.06 ± 0.02	0.58
Nonstudy coffee/tea consumed	0.03 ± 0.01	0.01 ± 0.01	0.90
Nonstudy salt/pepper/spices consumed	0.01 ± 0.01	0.01 ± 0.01	0.50

¹Values are means ± SEMs.

²P values from van der Weardan's test for differences between DGA and TAD. No significant differences were identified between the 2 groups.

vention for Blood Pressure Control) (24–26) were behavioral interventions that demonstrated associations between dietary pattern modifications with improved health outcomes (decreases in diastolic and systolic blood pressure). While these results are promising, they also relied primarily on self-reports for diet adherence. In an effort to strike a balance between high participant burden with increased observation compared with low participant burden with inadequate observation, we opted for a moderate participant burden and moderate surveillance. Participants only consumed breakfast meals with study staff twice a week, thus creating a more free-living setting. While this meant more reliance on self-report food logs, we also weighed back the returned containers to help reconcile the checklists and analyzed nitrogen in 24-h urine collections.

Urinary nitrogen recoveries (~80% of the dietary nitrogen measured in the 8-d diet composites of the TAD and DGA diets) indicated acceptable levels of adherence to the protein provided in the diets, as suggested by literature that indicates that urine nitrogen should be ~80% of dietary nitrogen in adults (16). That this value does not reach 100% is due to unmeasured routes of nitrogen flux, such as fecal nitrogen, skin, and other losses. Although this is truly an objective measure of adherence, a limitation in the present study was that we had to assume proportional protein content across the calorie levels provided, since the proximate analysis was only done for the 2200-kcal diets. Another potential pitfall with 24-h urine collections is that some urine collections might not have been complete. To mitigate this problem, if a participant reported that he or she missed a urination or spilled a large portion of the collection, we asked them to repeat the procedure on a different day within the same study week.

The DAQ was used as a measure of how acceptable the planned diets were. Based on responses from participants, both the DGA and TAD di-

ets were satisfactory, but neither was similar to or tastier than their usual diet. The extensive recipe testing and evaluation done prior to the trial likely contributed to the favorable evaluation of the diet. This suggests that it is possible to use a combination of canned, frozen, and fresh foods to plan and follow a diet based on the dietary guidelines that is satisfactory to the majority of participants.

In conclusion, this report demonstrates the challenges in designing, implementing, and monitoring a controlled-feeding study of dietary patterns in a free-living setting. One challenge identified was the difficulty of balancing recommended food patterns with providing adequate nutrition, particularly vitamins E and D, potassium, and dietary fiber. We also presented methods for monitoring adherence; in our hands, these methods suggested a high level of adherence to the diet plans. In addition, our study struck a good balance between the use of adherence measures with participant burden. One limitation is that we did not measure urinary sodium excretion as a possible indicator of dietary adherence during the intervention. Unlike dietary nitrogen, which was relatively constant between menu days, the variability in dietary sodium between the cyclic days of the menu would make a measure of 24-h urinary sodium excretion more difficult to interpret in terms of true adherence. To date, there is no set standard for realistically monitoring adherence in free-living controlled-feeding trials. Future studies need to use other approaches, including these, and standards should be set. This is pertinent, particularly because RCTs are allocated the highest evidence scores in establishing public health policies; however, in behavior or lifestyle interventions, adherence can be challenging especially in a “real world” setting (27). Not regulating or monitoring adherence or factoring adherence into the intent-to-treat approach could severely limit the external validity of RCTs.

TABLE 3 Mean percentages of energy and macronutrients provided that were consumed¹

Energy and select macronutrients	TAD	DGA	P ²
Energy provided, kcal	2250 ± 52	2221 ± 71	—
Energy consumed, kcal	2188 ± 50	2160 ± 66	0.51
% kcal consumed	97 ± 1	97 ± 1	0.26
% Fat consumed	96 ± 1	97 ± 1	0.23
% Carbohydrates consumed	97 ± 1	97 ± 1	0.48
% Protein consumed	97 ± 1	97 ± 2	0.46
% Fiber consumed	96 ± 1	96 ± 2	0.33

¹Values are means ± SEMs. Values were estimated by weighing back returned food containers. DGA, Dietary Guidelines for Americans; TAD, typical American diet.

²P values from van der Weardan's test for differences between DGA and TAD.

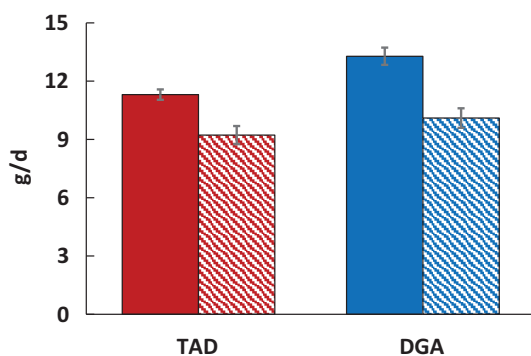


FIGURE 3 Dietary nitrogen intake and urinary nitrogen excretion in women consuming diets based on the the TAD or DGA diet. The solid bars represent the mean dietary nitrogen intake representing the respective intervention diets provided during the 8-wk study. The hatched bars represent the mean urinary nitrogen excretion measured from three 24-h urine collections taken at week 1, week 4, and week 7 of the intervention. The error bars represent the SEM. The percentage recovery (mean \pm SEM) of dietary nitrogen recovered in the urine was $81.9 \pm 4.0\%$ for TAD and $76.9 \pm 3.6\%$ for DGA. DGA, Dietary Guidelines for Americans; TAD, typical American diet.

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