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Comparing Self-Reported Dietary Intake to Provided Diet during a Randomized Controlled Feeding Intervention: A Pilot Study

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Abstract: Systematic and random errors based on self-reported diet may bias estimates of dietary intake. The objective of this pilot study was to describe errors in self-reported dietary intake by comparing 24 h dietary recalls to provided menu items in a controlled feeding study. This feeding study was a parallel randomized block design consisting of a standard diet (STD; 15% protein, 50% carbohydrate, 35% fat) followed by either a high-fat (HF; 15% protein, 25% carbohydrate, 60% fat) or a high-carbohydrate (HC; 15% protein, 75% carbohydrate, 10% fat) diet. During the intervention, participants reported dietary intake in 24 h recalls. Participants included 12 males (seven HC, five HF) and 12 females (six HC, six HF). The Nutrition Data System for Research was utilized to quantify energy, macronutrients, and serving size of food groups. Statistical analyses assessed differences in 24 h dietary recalls vs. provided menu items, considering intervention type (STD vs. HF vs. HC) (Student's *t*-test). Caloric intake was consistent between self-reported intake and provided meals. Participants in the HF diet underreported energy-adjusted dietary fat and participants in the HC diet underreported energy-adjusted dietary carbohydrates. Energy-adjusted protein intake was overreported in each dietary intervention, specifically overreporting beef and poultry. Classifying misreported dietary components can lead to strategies to mitigate self-report errors for accurate dietary assessment.

Keywords: 24 h dietary recall; dietary assessment; calories; protein; feeding intervention; systematic errors; random errors

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1. Introduction

Estimating dietary intake is challenging due to random and systematic bias in self-reported diets. To quantify food intake, most researchers rely on memory-based dietary assessments, such as food frequency questionnaires (FFQ), food records, and 24 h dietary recalls, which have been debated over their value and validity [1,2]. Random and systematic errors that may occur during memory-based dietary assessments include (a) respondent systematically overreporting or underreporting foods [3]; (b) respondent unintentionally including or omitting foods [4,5]; and (c) respondent unable to recall portion sizes [6]. Several previous studies have found that memory-based dietary assessments underreport energy intake using doubly labeled water [7–9]. For instance, older healthy adults were found to underreport energy intake using food diaries regardless of ethnicity [7,8]. Adults tend to underreport total carbohydrates [10], protein [11], specifically meat and dairy products [12], and snack foods [10]. Less is known about what types of foods within each macronutrient group are most likely to be misreported [13], with logical assumptions that foods with a negative health image (e.g., sweets) may be underreported and foods with a positive health image (e.g., fruits and vegetables) are more likely to be overreported [3]. Understanding specific foods that are typically misreported can be translated into the clinic to design assessment tools (e.g., food props) and methods (e.g., multi-pass questions) to facilitate accurate dietary assessment.

In controlled feeding studies, participants consume only foods and drinks that are prepared in the metabolic kitchen for an acute period. Although controlled feeding studies are labor-intensive and costly, they provide an opportunity to assess inconsistencies in memory-based dietary assessments against known provided meals [14]. The application of a 24 h recall to a controlled feeding study is not well understood, with several studies suggesting underreporting of macronutrients [15–18]. For example, a controlled feeding study in adults (n = 59) for twelve days demonstrated that subjects underreported energy intake by 5–21% using doubly labeled water [15]. Controlled feeding studies are analogous to eating meals outside the home, as participants have limited knowledge on how foods were prepared. Today, over a third of daily calories are consumed from foods prepared outside the home [19] and meals outside the home are associated with a higher total energy and fat intake [20]. Therefore, utilizing a controlled feeding study to assess the accuracy of memory-based nutritional assessments may elucidate shortcomings in nutritional assessment of premade meals.

The primary objective of this pilot study is to identify discrepancies in energy and macronutrient intake comparing self-reported intake assessed via 24 h dietary recall to food provided within a controlled feeding intervention. The secondary objective of this pilot study is to identify specific food groups that are typically misreported.

2. Materials and Methods

This report is a sub-analysis of a controlled feeding pilot study with a parallel randomized block design, called the Metabolomic Analysis of Diet (MEAL) study. The study was designed to test the metabolite response to two dietary interventions: a high-carbohydrate (HC) and a high-fat (HF) diet (Figure 1). Subjects were recruited using the University of Michigan research online portal (https://umhealthresearch.org, accessed on 1 July 2016). Participants included undergraduate and graduate students as well as community volunteers from the immediate vicinity. Inclusion criteria were age between 19 and 45 years, no history of metabolic disorders, body mass index (BMI) between 18.5 and 27, not currently taking metabolism-altering drugs and stable weight ±2 kg for the last 6 months. Exclusion criteria included food allergies, refusal to eat the food provided, need for special food considerations such as vegan, vegetarian, or religious food requirements, and regular smokers who had not stopped within the previous 6 months.

Participants included 12 males (7 HC, 5 HF) and 12 females (6 HC, 6 HF). Study visits occurred at the University of Michigan. Participants were randomly allocated to study intervention using a random number generator in Microsoft Excel. Randomization, enrollment, and assignment to dietary interventions were performed by the study team. The study team was not blinded to the assigned dietary intervention. Participants were blinded to their dietary intervention; however, it was easy to infer if they were on a HF or HC diet based on the foods given to them. The protocol is available on Deep Blue Repositories, through the University of Michigan library. This study was conducted between July 2016 and April 2017. The University of Michigan Medical School Institutional Review Board approved the study protocol and all participants provided written informed consent (HUM #000110543).

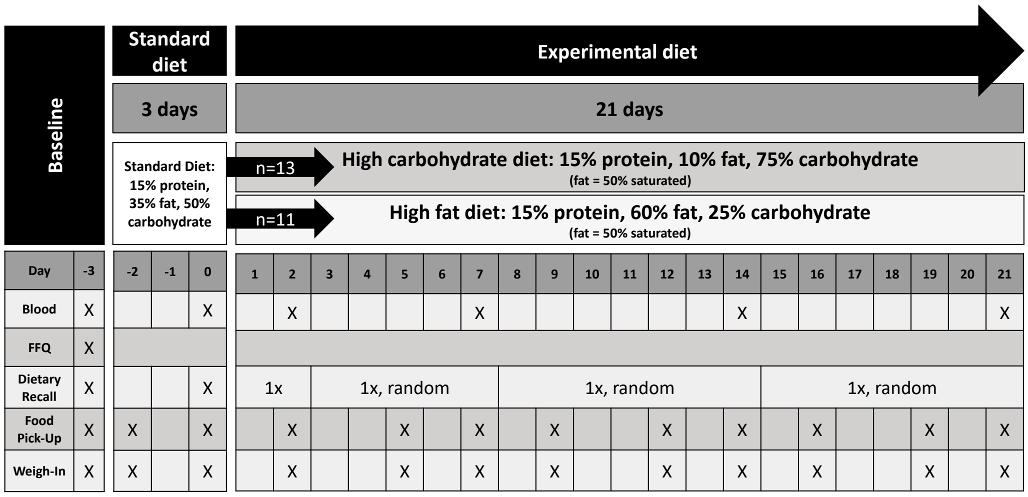

Figure 1. Metabolomic Analysis of Diet (MEAL) Study Design. All participants completed a standard diet followed by either a high carbohydrate or a high fat diet. Dietary recalls were collected up to six times throughout the study.

Baseline Visit. An initial study visit occurred with a Registered Dietitian (RD), a study coordinator, and a Registered Nurse (RN) or Licensed Practical Nurse (LPN) for an assessment of estimated energy intake, using the Institute of Medicine formulas [21]. Baseline body weight was collected in light clothing and stocking feet using a scale calibrated to the nearest 0.1 kg (Scale-Tronix Model 6002, White Plains, NY, USA). Baseline height was collected using a wall-mounted stadiometer in duplicate to the nearest 0.5 cm (Easy-Glide Bearing Stadiometer, Perspective Enterprises, Portage, MI, USA). The study team monitored participants' weight at each food pick-up visit. If body weight changed by $\geq$2.5%, total calories of experimental diets were modified to return to initial body weight. The proportion of macronutrients within each experimental diet remained constant.

Feeding Intervention. For 24 days, all meals and drinks were provided for the participants. Meals were created at the metabolic kitchen at the University of Michigan and were picked up by participants twice per week. All participants consumed a standard (STD) diet for 3 days (15% protein, 35% fat, 50% carbohydrate) prior to their random assignment to one of the two experimental diet groups for 21 days; the HF diet (15% protein, 60% fat with 50% SFA, 25% carbohydrate) or the HC diet (15% protein, 10% fat with 50% SFA, 75% carbohydrate). All dietary interventions were eucaloric. Participants were asked to consume all provided food and return any uneaten food to the lab on subsequent visits to be subtracted from total intake. However, very few participants abided by this request due to leftover food spoilage in the cooler and the inconvenience of saving uneaten foods. The study team made all possible accommodations for varied food preferences, sensitivities, and requirements for all subjects. Sample dietary menus are provided in Supplemental Table S1. A four-day rotating menu was utilized.

Dietary Assessment. During the baseline visit, participants received training on using measuring instruments (e.g., cups and spoon) and food props (e.g., deck of cards is equivalent to 3 oz of meat) during subsequent 24 h dietary recalls. All participants had access to a written copy of a food-amount-reporting booklet (adapted from [22]), which included scalable pictures of bowls, glasses, and mugs with fullness markings and pictures of different cuts of meat, chicken, and fish. The Nutrition Data System for Research (NDSR) software (version 2015) was used for dietary assessment (Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN, USA). All study RDs were certified in the collection of 24 h dietary recalls using NDSR, utilizing the multi-pass method for accurate assessment [23]. Up to six 24 h dietary recalls were conducted by study RDs, including at baseline (Day −3), during the standard diet (Day 0), and during the experimental diet

(Day 2 and three other random times) (Figure 1). NDSR was used to extract provided and self-reported calories, macronutrients, and food groups.

Statistical Analyses. Cohort demographics were compared between the HC and HF experimental groups (unpaired Student's *t*-test). Self-reported intake from the standard diet was quantified with a single 24 h dietary recall. Self-reported intake of calories and macronutrients from both experimental diets was quantified using an average across the 24 h dietary recalls. Self-reported intake of food groups from both experimental diets was analyzed separately for each 24 h dietary recall to reflect differences in the types of foods from the rotating experimental menu. Reported macronutrient intake was adjusted for total energy intake, calculating the percent calories from each macronutrient. Food groups were reported in number of servings. Percent difference between provided menu and self-reported servings of food groups was quantified using the equation (reported − provided)/[(reported + provided)/2] × 100. All statistical analyses comparing provided menu items and self-reported intake utilized paired Student's *t*-tests. Statistical significance was described using a $p < 0.05$. All data analyses were performed using R version 4.0 [24].

3. Results

3.1. Description of Dietary Comparisons

Participants were 24 years old (19–32) on average, with a mean BMI of 22.8 kg/m^2 (18.3–26.2). The BMI range spanned underweight (BMI < 18.5, n = 1), normal weight (18.5 ≤ BMI < 25, n = 17), and overweight (25 ≤ BMI < 30, n = 6). There were no significant differences in baseline weight, age, or BMI between the HC and HF experimental groups (Supplemental Table S2). Twenty-four participants (100%) completed the study. A 24 h dietary recall was completed by 14/24 participants during the STD diet. During the HC diet, participants completed one (one participant), two (two participants), or three (nine participants) 24 h dietary recalls. During the HF diet, participants completed one (one participant), two (two participants), three (eight participants), or four (one participant) 24 h dietary recalls.

3.2. Discrepancies in Energy and Macronutrient Intake between Dietary Recall vs. Provided Meals

No caloric intake differences were observed between self-reported vs. provided meals in either the STD, HC, or HF diets (Table 1). Small differences (grams) of macronutrients in the diets were observed between self-reported intake vs. provided meals (Table 1). In the STD diet, participants reported a higher amount of protein than provided (123 g reported vs. 95 g provided, $p = 0.03$), specifically overreporting animal protein (86 g reported vs. 63 g provided, $p = 0.04$). In the HC diet, participants reported a higher amount of fat than provided (55 g reported vs. 34 g provided, $p = 0.003$). To extrapolate on these results, we compared differences in the type of fat—saturated, monounsaturated, and polyunsaturated—between self-reported intake vs. provided meals (Supplemental Table S3). In the HC diet, grams of saturated, monounsaturated, and polyunsaturated fat were significantly overreported. Macronutrients were adjusted for total energy intake using daily calories, as the amount of food each participant was provided varied by their weight, age, and sex per the Institute of Medicine equations. Adjusting for total energy intake demonstrated multiple discrepancies in provided vs. self-reported diets (Figure 2). In the STD diet, participants reported a higher percent of protein than provided (18% reported vs. 14% provided, $p = 0.0004$), with no observed differences in the percentage of carbohydrates and fat reported vs. provided. In the HC diet, participants reported a higher percent of protein than provided (17% reported vs. 15% provided, $p = 6.1 \times 10^{-4}$), a higher percent of fat than provided (18% reported vs. 11% provided, $p = 8.5 \times 10^{-9}$), and a lower percent of carbohydrates than provided (65% reported vs. 74% provided, $p = 7.4 \times 10^{-9}$). In the HF diet, participants reported a higher percent of protein than provided (17% reported vs. 15% provided, $p = 0.03$), a lower percent of fat than provided (54% reported vs. 60% provided, $p = 3.7 \times 10^{-5}$), and a higher percent of carbohydrates than provided (29% reported vs.

25% provided, $p = 0.01$). The type of fat was adjusted for total energy intake (Supplemental Table S4). In the HC diet, percent caloric intake of saturated, monounsaturated, and polyunsaturated fat was significantly overreported. In the HF diet, percent caloric intake of saturated fat was the only significantly underreported type of fat (23% reported vs. 28% provided, $p = 0.0002$).

Table 1. Absolute quantities of calories and macronutrients, stratified by the type of diet. Values are mean ± standard deviation. *p*-value < 0.05 is bolded.

	Provided Intake	Reported Intake	*p*-Value
standard diet			
calories (kcal)	2676 ± 498	2726 ± 668	0.82
carbohydrates (g)	328 ± 70	322 ± 88	0.86
fat (g)	115 ± 35	109 ± 35	0.68
protein (g)	95 ± 19	123 ± 41	**0.03**
high-carbohydrate diet			
calories (kcal)	2777 ± 495	2823 ± 991	0.88
carbohydrates (g)	535 ± 97	479 ± 171	0.32
fat (g)	34 ± 9	55 ± 21	**0.003**
protein (g)	103 ± 19	119 ± 41	0.23
high-fat diet			
calories (kcal)	2722 ± 496	2791 ± 565	0.77
carbohydrates (g)	173 ± 33	205 ± 55	0.12
fat (g)	185 ± 34	171 ± 37	0.36
protein (g)	101 ± 18	116 ± 28	0.15

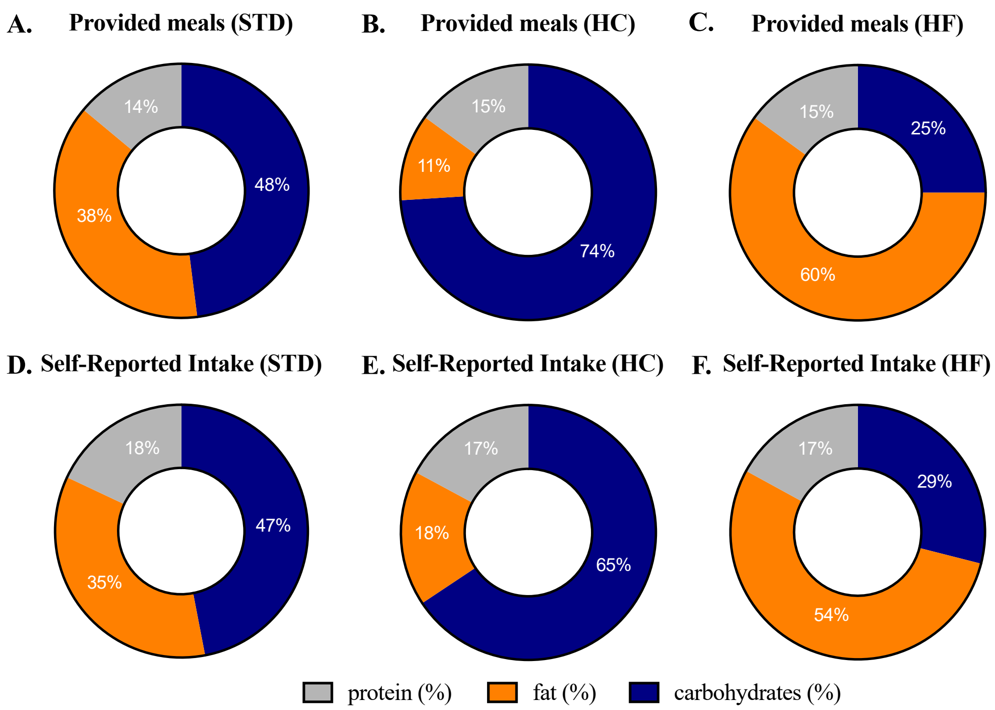

Figure 2. Macronutrient intake expressed as a percentage of total energy intake for provided meals during (**A**) standard (STD), (**B**) high-carbohydrate (HC), and (**C**) high-fat (HF) diets and self-reported intake during (**D**) standard, (**E**) high-carbohydrate, and (**F**) high-fat diets.

3.3. Discrepancies in Servings of Food Groups between Dietary Recall vs. Provided Meals

Foods were classified into servings of food groups in NDSR and self-reported vs. provided servings of the food groups were compared for each dietary intervention (Supplemental

Table S5). Percent difference in reporting meats, eggs, milk products, and additives are represented in Figure 3. Several differences were observed comparing the self-reported vs. provided number of servings in the STD diet, with an overreporting of lean poultry ($p = 0.001$), an overreporting of reduced-fat cheese ($p = 0.05$), and an underreporting of butter ($p = 0.0003$). Many differences were observed comparing the self-reported vs. provided number of servings in the HC diet, with discrepancies in reporting whole- vs. refined-grain breads, regular vs. lean beef, and regular vs. reduced-fat salad dressings. Overall, individuals in the HC diet overreported beef ($p = 0.0002$), lean poultry ($p = 0.034$), full-fat cheese ($p = 0.044$), yogurt ($p = 0.005$), and reduced-fat margarine ($p = 0.001$). Several differences were observed between the self-reported vs. provided number of servings in the HF diet, including overreporting pasta ($p = 0.012$), overreporting yogurt ($p = 0.05$), and underreporting butter ($p = 0.001$). There were very few discrepancies between the self-reported vs. provided number of servings of fruits and vegetables across each dietary intervention.

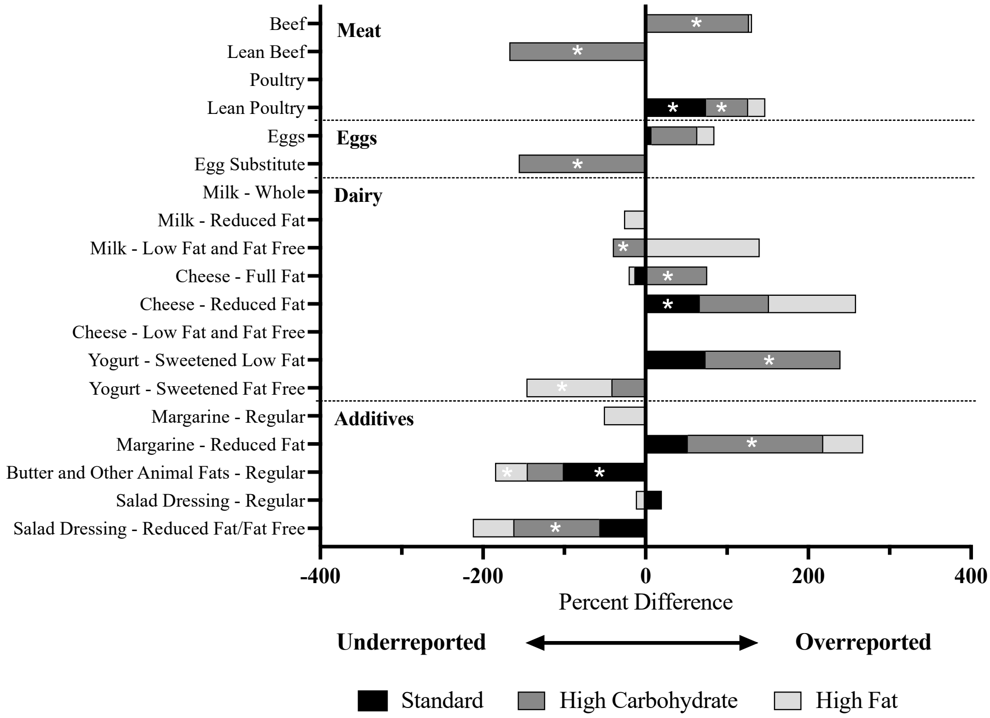

Figure 3. Percent difference in reporting meat, eggs, dairy, and additives stratified by dietary intervention. Percent difference reported as an additive effect by stacking bars for each dietary intervention. Significant differences between self-reported vs. provided servings of the food groups denoted with a white "*" (p-value < 0.05).

4. Discussion

Dietary assessment methods based on self-report are prone to systematic and random errors [1,2]. The objective of this study was to compare self-reported dietary intake using 24 h recalls to provided menu items in a controlled feeding intervention. Self-reported energy-adjusted protein intake was greater than provided protein in each of the diets (Figure 2). This was specifically attributed to overreporting of animal protein, including beef and poultry (Figure 3), demonstrating the challenges in quantifying the size of a serving of meat. To our knowledge, three previous studies have measured differences in self-reported vs. actual intake of animal protein, with two studies finding underreporting [12,25] and one study finding no differences [26]. Additionally, we observed discrepancies in reporting fat content in meats (e.g., regular vs. lean beef in the HC diet), which may have contributed to the increased self-reported intake of saturated fat in the HC diet (Supplemental Table S3). The NDSR food prop booklet that participants used for this study includes several depictions of steaks, poultry pieces, and filets; however, many animal protein foods that people eat are in the form of casseroles, dishes, and stews, which can make the amount and the type of fat within the protein source challenging to quantify. Recent attempts to increase the accuracy of dietary recalls include using digital images of foods (e.g., Automated Self-Administered 24-h [ASA-24] Dietary Assessment Tool) [27], increasing the number of multi-passes (e.g., Automated Multiple-Pass Method [AMPM]) [28], and text-based descriptions of portion sizes [29]. Understanding and addressing the limitations in the quantification of animal protein within dietary recalls is important as many epidemiologic studies draw conclusions about animal protein- and nutrition-related chronic conditions [30].

All the meals within this controlled feeding study were premade and included lasagna, cream of broccoli soup, and breakfast sandwiches. Therefore, it can be considered that our study is analogous to eating premade foods outside of the home (e.g., restaurants and take-out), in which foods are often misreported due to preparation differences. Importantly, our experimental diets were designed to be excessively high in fat or carbohydrates to support our primary aim of assessing the metabolite response to a high-fat or high-carbohydrate acute interventions (manuscript pending). Underreporting percent calories from fat in the HF diet and underreporting of percent calories from carbohydrates in the HC diet may be attributed to this design, in which the experimental diets were exaggerated from a typical dietary pattern. For instance, the HF diet utilized "hidden" fats in dairy products (e.g., half and half and butter), dishes (e.g., cheesy potato bisque), and meats (e.g., sausage links), which may have contributed to the underreporting of caloric intake of saturated fat in the HF diet (Supplemental Table S4).

Our study is relevant to current eating patterns, as the consumption of food prepared outside of the home has increased through the years [19]. In adults in 2011–2012, premade food eaten outside of the home contributed to 34% of daily caloric intake, growing from 17% in 1977–78 [19], demonstrating the necessity of creating tools to help measure nutritional information in premade meals. It is postulated that with advances in artificial intelligence, digital technology (e.g., mobile applications and wearable technologies) can provide real-time collection of dietary data without the need for self-reports [31]. For instance, researchers have developed wearable cameras that capture food images with sensors to monitor meal intake (e.g., Automatic Ingestion Monitory 2 [AIM-2]) [32]. The assessment of dietary intake by wearable sensors and application is a strong area of research; however, it is necessary to increase accessibility and technical assistance for these technologies prior to translating them into the clinic [33]. Furthermore, current artificial intelligence technologies may not adequately quantify high-caloric food additives in meals, such as butter.

The strengths of our study include its longitudinal experimental design with the comparison of three different dietary interventions with varying macronutrient composition. Multiple 24 h recalls were collected from participants during the experimental diet by trained Registered Dietitians using the multi-pass methods in NDSR; however, most participants were not able to be contacted for all four 24 h recalls in the experimental diet. Analyses compared self-reported intakes to provided meals; however, we cannot be certain if the participants ate all the provided foods, as a limitation of this study was that most participants did not return uneaten foods to the clinical research unit due to its inconvenience and high levels of food spoilage. Our study included an equal distribution of males and females; however, we only recruited a small sample size of "healthy" young adults, limiting the generalizability of our study. Of interest, previous studies have demonstrated that individuals with obesity underreport their dietary intake [34]. In a sub-analysis, we did not observe any significant associations between BMI and misreporting dietary intake, potentially due to the small range of BMI in the cohort; however, a non-significant trend was observed that individuals with a higher BMI underreported calories in the HF diet ($p = 0.18$). Future work on this study question should consider a wider range of BMIs spanning several weight status categories. Our main objective for the MEAL study is to classify metabolite biomarkers of high fat and high carbohydrate intake; therefore, we created the menus with specific food adaptions to exaggerate either fat or carbohydrate intake that may have been unknown to participants (e.g., regular vs. low-fat ingredients). This may have increased misreporting of specific food groups (e.g., regular vs. lean beef); however, certain trends were observed across multiple diets (e.g., overreporting poultry). Further, subjects were not screened for binge eating disorders or other psychosocial conditions which may contribute to inaccuracy known to affect dietary recall [35].

5. Conclusions

Our results provide preliminary data suggesting that specific protein-rich food groups, including poultry and beef, tend to be overreported in a 24 h dietary recall. Furthermore, we observed that individuals on a high-macronutrient diet tend to underreport their most abundant macronutrient. Future directions include expanding this preliminary study to test additional dietary interventions with a range of macronutrients compositions. Future work should consider comparing self-reported 24 h recalls and artificial intelligence sensors in a controlled feeding study, utilizing specifically targeted mobile applications that are freely available to the general population. Future work should consider recruiting case vs. control patients, targeting disease states in which nutritional analysis has high implications. Studies with larger and more diverse study populations should be conducted to strengthen and extend the generalizability of these results.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/dietetics2040024/s1, Supplementary Table S1. Samples menus of food provided to participants, Supplementary Table S2. Subject characteristics in MEAL study, stratified by type of dietary intervention, Supplementary Table S3. Absolute quantities of saturated, monounsaturated, and polyunsaturated fatty acids, stratified by the type of diet, Supplementary Table S4. Percent of caloric intake of saturated, monounsaturated, and polyunsaturated fatty acids, stratified by the type of diet, & Supplementary Table S5. Differences between actual and self-reported number of servings of food groups, stratified by experimental diet.

Author Contributions: Conceptualization, C.F.B. and K.E.P.; methodology, J.L.C., H.B.I., S.C.B., T.L.H.-M., C.F.B. and K.E.P.; formal analysis, J.L.C., J.L.M. and T.M.B.; investigation, J.L.C.; resources, C.F.B. and K.E.P.; data curation, J.L.C., J.L.M. and T.M.B.; writing—original draft preparation, J.L.C., J.L.M., C.F.B. and K.E.P.; writing—review and editing, all authors; visualization, J.L.C. and J.L.M.; supervision, C.F.B. and K.E.P.; project administration, S.C.B. and T.L.H.-M.; funding acquisition, C.F.B. and K.E.P. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The Michigan Institutional Review Board approved all procedures involved in this study (HUM00006248, HUM000110543 and HUM00045653) and we obtained informed consent forms from all participants before beginning any portion of the study. All recruitment of participants for each of the studies described herein used umclinicalresearch.org and local advertisements.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data described in the manuscript, code book, and analytic code will be made available upon request.

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Conflicts of Interest: The authors declare no competing financial interest.

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