DIETITIAN-LED PROGRAMMING AND CREATION OF A MOBILE APPLICATION, MEALPLOT, TO INDUCE SUSTAINABLE AND SIGNIFICANT WEIGHT LOSSES IN OBESE ADULTS

BY

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THESIS

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ABSTRACT

Introduction

National and international rates of overweight and obesity have dramatically risen in recent decades due to changes in the global food landscape. Overweight and obesity are linked to many health problems: cardiovascular disease, hypertension, diabetes, elevated cancer risk, and others. Despite best efforts, a sustainable weight management solution does not exist. Existing programs are high cost, have low success rates, and low sustainability. The Individualized Dietary Improvement Program (iDip) and MealPlot mobile application are two projects aiming to develop a weight management program that leads to sustainable weight losses of greater than 5% initial body weight, contributes to healthful dietary changes, and is lower in cost than previous, similarly successful programs.

Methods

iDip was a two-year before and after study design without a control group. It occurred in-person at the University of Illinois Urbana-Champaign from March 2019-2021. Thirty participants from the surrounding community were enrolled and completed 19 in-person dietitian-led education sessions, three individual advising meetings, dietary monitoring via 24-hour dietary records and food frequency questionnaire, body composition and measurements, and daily self-weighing. Dietary records were collected bi-monthly throughout year 1; food frequency questionnaires at baseline, 12 months, 24 months; and body composition, waist and hip circumference at baseline, 6 months, 15 months, and 24 months. Participants received individualized feedback via weekly weight monitoring charts and the novel, protein-fiber food displays. Outcomes were analyzed using mean, Students t-test, and regression analysis.

MealPlot was developed in coordination with the University of Illinois Urbana-Champaign Applied Research Institute from January 2020-Present. Strategies from iDip 2,

namely protein-fiber food displays, weight charts, health assessment, and communication with advisors, are heavily utilized in the application. MealPlot was developed on a HIPAA-secure server pulling data from the USDA Nutrition Database and the participant's Wi-Fi scale.

Results

At 12 months, 22 participants (73.3% retention, 13 females) remained enrolled. Mean baseline age and body mass index were 49.3 (11.5, SD) years and 37.4 (5.1) kg/m^2, respectively. Mean weight loss was -6.5 (8.4)% and mean body mass index change was -2.33 kg/m^2. Weight loss primarily occurred in the first six months, and early weight losses were predictive of long-term weight losses. On both the food frequency questionnaires and dietary records, participants significantly increased protein ($p<1e-6$) and fiber ($p<0.001$) densities and significantly reduced caloric intake ($p<0.01$) and intake of non-nutrient dense foods ($p<1e-4$). iDip 2 had insignificant improvements in weight loss versus iDip 1 and was significantly lower in cost than similarly successful programming.

The three core features of MealPlot were developed and internally tested: Meal Planner, One Day Record, and Weight Chart. MealPlot will be incorporated in the EMPOWER programming.

Conclusions

iDip lead to clinically significant weight losses in many participants. However, weight losses were highly variable among participants. Dietary improvements were significant but inconsistent among dietary records. Follow-up studies and larger cohorts are needed to identify the sustainability of weight losses and dietary changes. MealPlot's core features are fully developed and await incorporation into the EMPOWER program. Based on participant feedback, MealPlot will be updated with additional features.

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CHAPTER 1. Introduction

National and worldwide obesity rates are rising due to significant changes in the food landscape, such as the increased availability of calorically dense and nutrient-poor foods, reduced fiber intake, and high intakes of added sugar and animal fat [1]. At its core, obesity is caused by a chronic positive energy balance resulting from excessive food intake and physical inactivity. In the United States, 70.2% of adults are obese (BMI>30) or overweight (BMI>25), with 7.7% being extremely obese (BMI>40) [2]. Utilizing recent (2013-2016) National Health and Nutrition Examination Survey (NHANES), 36.5% and 40.8% of US men and women, respectively, were obese [3]. Obesity also affects 18.5% of US children and adolescents, increasing their likelihood of adult obesity and suffering obesity-related complications at a young age [4, 5]. Incidence rates of abdominal obesity have increased 12.9-15.5% between 1988 and 2010 [3]. The cost of obesity on the nation's health listed, in large part due to the comorbidities discussed below, is upwards of 147 billion USD annually [6].

Non-communicable disease rates, such as type 2 diabetes mellitus (T2DM), coronary heart disease (CHD), stroke, metabolic syndrome, and several cancers, increase concurrently with obesity [7]. Additionally, obesity is associated with increased all-cause mortality risk [6]. The aforementioned chronic diseases are often caused and resolved by a change in body weight. Sustained weight changes of at least 5% initial bodyweight improve metabolic and cardiovascular health markers, such as insulin sensitivity [8].

As a result of adverse health and economic impacts, a sustainable and cost-effective obesity reduction program is needed. However, as discussed in "Chapter 2. Literature Review", such a program does not currently exist. Existing programs and initiatives, such as Look AHEAD, Weight Watchers, Diabetes Prevention Program, lack substantial weight losses,

sustained weight losses and health benefits, and cost effectiveness.

Despite extensive resources devoted to weight management programming, currently available programs lack safety, efficacy, sustainability, and cost-effectiveness. Key limitations when studying weight loss are short follow-up periods and weight regain. In addition to weight loss magnitude, it is important to study changes in diet, body composition, and health markers, including blood lipids, blood pressure, and glucose control.

The studies discussed here, Individualized Dietary Improvement Program (iDip) and MealPlot, are efforts to design a cost-effective weight management program on the basis of empowering individuals to make informed dietary decisions using novel tools, namely the Protein-Fiber plot and weekly weight progress chart. iDip and MealPlot aim to address issues seen in previous programs: safety (lack of monitoring for muscle mass decline), efficacy (weight loss achieved), sustainability of weight loss, and cost-effectiveness.

CHAPTER 2. Literature Review

Weight management programming

In-person programming and medical approaches

Contemporary weight loss programs often rely on a significant caloric reduction, at least 25% daily intake, daily calorie counting, meal replacements, a substantial shift in macronutrient composition, or a combination. The 2001 Look AHEAD (Action for Health in Diabetes) intensive lifestyle program utilized restricted energy diets, exercise programming, self-monitoring, dietitian advising, and meal replacement programs. While participants successfully lost >5% initial bodyweight after one year, regain began shortly after one year and health benefits achieved, such as improved glycemic control and reduced blood triglycerides, declined over the ten-year follow-up period [9]. The Diabetes Prevention Program (DPP), similar to Look AHEAD with the addition of pharmaceuticals, resulted in weight losses >5% after one year with significant weight regain following [10]. Weight Watchers, a commercialized program focusing on an energy-restricted and balanced diet, also had low sustainability; of members who reached a goal weight (healthy BMI), less than one-third were within five pounds of their goal weight after five years [11]. As shown by these programs, weight loss sustainability is a crucial issue.

Changes in macronutrient composition, such as the restriction of carbohydrates in the ketogenic diet or fat in the Ornish, are popularized approaches to weight management with mixed results. These diets have led to substantial short-term weight losses, such as a 7.2% weight reduction in a ten-week ketogenic diet study [12]. Weight loss studies comparing the Ornish and ketogenic diets, “extreme diets”, to Weight Watchers or conventional low-fat diets, “moderate diets”, favor the extreme diets short term. However, after 12 months, weight regain occurs, and there is no significant difference between the extreme and moderate diet groups [13, 14]. Individuals are likely unable to make lifelong adaptions to maintain these diets accounting for

both weight regain and increased attrition in the extreme diet groups. It is critical that a diet be individualized if it is to be sustainable.

Daily dietary recording, via paper-and-pencil or mobile application, can lead to weight loss success [15, 16], but it is time-consuming, frequently inaccurate, and can lead to greater attrition [16-18]. However, calorie counting is only effective if 1) the patient accurately records calories of every food and beverage consumed, 2) the patient adheres to a calorie goal that results in a chronic energy deficit.

A self-monitoring alternative to calorie counting and food journaling is the use of daily self-weighing and frequent quantitative feedback. Studies by Bertz et al. [19] and Rosenbaum et al. [20] found reduced weight gain in college women when they self-weighed daily. The WEIGH study found that overweight and obese adults who weighed daily lost significantly more weight and adhered to more weight control strategies based on the validated Weight Control Strategies Scale [21, 22].

When lifestyle interventions are insufficient for weight loss, pharmaceuticals can be utilized. The Food and Drug Administration has approved only a handful of obesity pharmaceuticals: Orlistat, Phentermine-topiramate, Naltrexone-bupropion, and Liraglutide [23]. Only Alli is available over-the-counter and is a small dosage of Orlistat. Orlistat and Alli work by reducing the amount of fat absorbed from the diet in the small intestine, which can impair fat-soluble vitamin absorption. The remaining pharmaceuticals work via appetite suppression. In long-term studies of Orlistat + Diet versus Diet-only, Orlistat increased weight loss by 2.9%, and weight regain after one year was similar across both study groups [24]. Phentermine-topiramate had greater efficacy inducing 6.6-8.6% (dosage dependent) weight losses in the year-long phase 3 trial [25]. Naltrexone, an opioid-addiction medication, combined with the anti-depressant

bupropion lead to weight losses of 5.2% compared to the placebo in year-long phase 3 trials [26]. It is less effective compared to phentermine-topiramate. Weight management pharmaceuticals have several side effects, most commonly nausea, stool consistency changes, insomnia, and headache.

For the severely obese, BMI ≥40 or BMI ≥35 with a co-morbidity, bariatric surgery is an alternative treatment when lifestyle and pharmaceutical interventions fail [27]. Four types of surgical interventions are available: laparoscopic adjustable gastric band, gastric sleeve, Roux-en-Y gastric bypass, and the duodenal switch [28]. Gastric band and bypass are most commonly performed as they have the highest benefit:risk ratio [29]. Only the gastric band is easily reversible, as a band is inserted around a portion of the stomach to reduce capacity. The remaining surgeries remove a portion of the intestines or reroute the intestines. These procedures have been shown to drastically improve weight status [30] and significantly reduce all-cause, cardiovascular, and diabetes mortality [31]. Bariatric surgery has also been shown to improve body image, quality of life, and general self-efficacy, indicating several positive effects [29].

Surgical interventions, while effective, present several drawbacks. First, procedural costs average $14,389/surgery with a range of $7423-$33,541 [32]. Second, surgical complications, such as pulmonary complications, hernias, and fistulas, occur infrequently [33]. Nutritional complications, however, occur more frequently due to the malabsorptive nature of the bypass surgery [33]. Various vitamin and mineral deficiencies, including Calcium, Iron, and B-vitamins are common. As such, patients require lifetime supplementation in addition to increased protein intake and a highly restrictive post-operative diet [34].

Virtual programming

Above, in-person, surgical, and medical approaches to obesity treatment were discussed.

In the following paragraphs, the accessibility, effectiveness, sustainability, and challenges of virtual obesity interventions will be discussed. The number of virtual programming and mobile health (mHealth) applications has increased substantially as the rates of adult and pediatric obesity rise. Over 300,000 mHealth applications targeting dieting and weight loss are now available, with some like MyFitnessPal being downloaded 50 million times [35]. Unlike in-person programming, virtual programming offers a lower cost intervention and the ability to reach traditionally hard-to-reach populations, such as low-income or minority groups. Pew Research Center reports that over 80% of the US adult population owns a smartphone, over two-thirds of adults earning <$30,000 own a smartphone, and nearly 80% of Hispanic and African American adults own a smartphone [36].

A 2020 review by Ghelani et al. showed applications have led to significantly greater weight losses in adult populations with overweight, obesity, metabolic syndrome, and diabetes [37]. Meta-analyses have shown that in randomized controlled trials utilizing mobile applications as a standalone treatment or supplementary treatment, participants who use the mobile application lose significantly more weight than those in a control group [38, 39]. This effect was most substantial in obese populations and in studies where the mobile application was a part of the treatment, not a standalone intervention.

Mobile applications developed commercially and by academia contain a variety of different strategies: self-monitoring of diet, exercise, sleep; goal setting; healthy eating support through information or skill development; physical activity support; social support; health assessment; motivational support; and personalized feedback [40]. The most common strategy is self-monitoring [40], such as through calorie counting. While a simple calorie counting application (MyFitnessPal) alone did not lead to substantial weight changes [41], self-monitoring

applications with education and feedback components did lead to significant weight losses in comparison to paper journals and usual care [42-44]. These studies support the need for a weight management application that is supplemented by additional interventions.

The limited sustainability of weight loss plagues current programs. Mobile application studies for weight loss are often on the scale of weeks to months, rather than years like Look AHEAD, making sustainability difficult to assess. However, an application that successfully induces weight losses is theoretically more sustainable than in-person interventions because applications are 1) accessible at any time and place increasing their convenience; 2) more empowering to consumers because information to make health decisions is at their fingertips; and 3) longer lasting because in-person programming typically has a timeline of months to years, whereas a mobile application could be used over a lifetime. Applications specifically targeted for weight maintenance after losses of greater than 5% initial bodyweight have shown success in sustainability. For example, the MotiMate application prompted users to track their daily weight, food intake, physical activity, and mood. Participants did not experience significant regain in the 24-week period [45]. While it is currently unclear that weight lost via mobile application-mediated programs is more sustainable, it has been shown that these programs achieve greater retention and treatment adherence than their non-technological counterparts [42, 43].

CHAPTER 3. Individualized Dietary Improvement Program 2

Introduction

The iDip study was designed to help participants develop a sustainable weight loss diet through education, counseling, and self-experimentation. iDip 2 builds off the success of iDip 1 where participants underwent a similar intervention and lost a mean 5.35% bodyweight (n=12). From iDip 1 to iDip 2, we revised the education materials, and the following items were added: periodic body composition, longer follow-up period (6 months vs. 12 months), and short homework and feedback assignments. The objectives of iDip 2 were to 1) increase the success rate and magnitude of weight loss, and 2) identify factors that differentially affect weight loss success rates.

Within the project, I had the following responsibilities: develop and present session materials, counsel participants, data collection and analysis, serve as the institutional review board contact, and communicate with participants during the one-year follow-up period.

Methods

This study was approved by the University of Illinois Urbana-Champaign Institutional Review Board, #18069. The study was registered at the US National Institutes of Health (ClinicalTrial.gov) #NCT04605653. Informed consent was obtained from all participants included in the study.

Study Design

iDip 2 is a two year before and after weight loss intervention trial. The first 12 months, March 2019-March 2020, of iDip 2 consisted of 19 group educational sessions and three individual advising sessions. Curriculum and timeline is detailed in Table 1. Education sessions were 50 minutes long and consisted of a 30-minute lecture, skill-building activities, and discussion. After each session, participants submitted a feedback and homework assignment via the secure Box (https://www.box.com/home, Redwood City, CA) where instructors

communicated about weight loss difficulties and food choices. Year two is a follow-up period focused on weight maintenance where participants report weights daily. While year two did not have any formal educational sessions, participants were contacted weekly by their adviser with motivational messaging and their weight progress charts (Figure 1). Participants were encouraged to frequently communicate with their adviser and seek advice as needed. Participants struggling with non-dietary barriers to weight loss, such as stress, were offered the opportunity to meet with the iDip social work team led by Dr. Janet Liechty.

Recruitment

Participants were recruited via University of Illinois electronic staff newsletters, posters in campus buildings, word-of-mouth, and flyers in Carle Foundation Hospital physician offices. Utilizing the standard deviation from previous studies [46-48], a power calculation was performed for 95% confidence. A sample of at least 19 was needed. To account for attrition, 30 participants were recruited.

Prospective participants contacted investigators and received a detailed description of the study. Interested participants completed a consent form and medical history form prior to meeting with investigators. Selected participants attended a meeting with investigators where baseline anthropometrics were measured. Inclusion criteria: aged 18-70 years old, overweight or obese BMI (BMI>25 kg/m^2; BMI>23 kg/m^2 if Asian), not pregnant or lactating, Wi-Fi and smartphone access, no self-reported severe metabolic, cardiovascular, or musculoskeletal problems; not using insulin injection, willing and able to attend 22 dietary improvement sessions, lose $\geq$ 9.1 kg (20 lb) and maintain the loss, and self-weigh daily for 24 months; and fluent in English speaking and writing. Exclusion criteria included failure to submit the food frequency questionnaire and set up Wi-Fi enabled scale.

Outcome Measures

Anthropometrics

Participants self-weighed daily on a WiFi-enabled scale (Withings, Issy-les-Moulineaux, France). These weights were transmitted to researchers who compiled a weekly weight trend chart (Figure 1). At zero, six, and 15 months, we collected body composition, height, weight, hip and waist circumference. Height was measured to the nearest 0.64 cm (0.25") with shoes removed using a stadiometer (Seca 700, Hanover, MD, US), and weight was measured to the nearest 0.05 kg (0.1 lb) on the same instrument. Waist and hip circumference were measured to the nearest 0.1 cm using a standard, retractable measuring tape (Gulik II, Gay Mills, WI, US). For the complete study timeline, including outcome measures, see Table 1.

Body Composition

Body composition was measured at baseline, six months, and 15 months via electrical impendence (InBody USA, Cerritos, CA, US). Measurements at 15 months were initially scheduled to occur at 12 months but were delayed due to the US SARS-CoV-2 outbreak. To accommodate those with virus-related concerns, the measurements at 15 months were optional and not fully representative of the cohort.

Dietary record collection

At baseline (pen-and-paper format) and 12 months (electronic format), a food frequency questionnaire (FFQ) was administered. The FFQ was modified from the European Prospective Investigation of Cancer (EPIC)-Norfolk questionnaire [49]. 24-hour dietary records were administered using a pen-and-paper format six times. 24-hour dietary records were analyzed, and feedback was provided to participants in a Protein-Fiber plot [50] (Figure 2). The US Department of Agriculture National Nutrient Database for Standard Reference (https://fdc.nal.usda.gov/) and manufacturer information were used to calculate protein and fiber density.

24-hour dietary records were also separated into their individual protein and fiber compositions based on van Baak et al. [51], using: cereal [52] and non-cereal fibers (NCF), cereal and non-cereal proteins (NCP), red meat protein, poultry protein, fish protein, egg protein, and dairy protein. Further calculations were: total plant protein (TPP), sum of cereal and NC protein; total animal proteins [53], sum of red meat, poultry, fish, egg, and dairy proteins; total meat protein (TMP), sum of red meat and poultry proteins. Mixed foods were estimated in their composition. TAP and TPP were used in correlation analysis as a percentage of total protein.

Cost Analysis

The iDip program's costs were estimated based on dietitian-labor hours based on an hourly salary of $29.97 [54]. Research-related cost, facility cost, and employee benefits cost were excluded from this estimate. When comparing to past programs, costs were inflated to the March 2020 USD, time of conclusion for iDip, according to the US Bureau of Labor Statistics Consumer Price Index Inflation Calculation (https://www.bls.gov/data/inflation_calculator.htm). All program-specific dietitian labor was included in this estimate: session delivery (19 sessions delivered three times each), individual advising (three 30-minute sessions/person), weight chart updates and weekly messaging (one message and chart/week/person), dietary assessments (pre- and post-intervention FFQ and six 24-hour dietary records), anthropometrics and body composition measurements at baseline, six months, and 15 months, and summary reports at baseline, six months, and 15 months. Wi-Fi-enabled scales were also factored into the program cost. One scale costs $59.95, and with a 10% replacement cost, each scale costs $65.95, and one scale was needed per participant. Scales provided to participants who later left the program were not factored into the cost because the scales were returned to the research team for future program use.

Statistical Analysis

Descriptive analysis was used to summarize demographic characteristics. Weight loss of ≥5% from the baseline was considered successful as it has been shown to reduce health risks associated with obesity [55]. Participants were divided into three groups based on the weight loss of 12 months; top, middle, and bottom tertiles. Paired and unpaired t-test analyses determined the pre- and post-intervention differences in outcome measures. Pearson correlation analyses were performed to determine associations between body weight, protein density, and fiber density. Chi-square analysis was used for the frequency of daily weighing. All statistical and food records analyses were performed using Microsoft Office Excel 2016 or R Computing (Version 3.6.1 © 2019), and $p<0.05$ was considered statistically significant.

Results

Participants

At baseline, 30 participants (19 females) were enrolled with demographics listed in Table 2. The mean age was 49.3 (SD=11.7) years, and the mean BMI was 37.3 (6.1) kg/m^2. Enrolled participants had medical histories of skeletal problems (50% of enrolled participants), hypercholesterolemia (46.7%), hypertension (33.3%), sleep apnea (33.3%), irregular periods (30% of enrolled females), depression (26.7%), type 2 diabetes mellitus (26.7%), thyroid problems (20%), kidney problems (10%), muscle pain (6.7%), osteoporosis (6.7%), nonalcoholic fatty liver (3.3%), hyperlipidemia (3.3%), polycystic ovary syndrome (3.3%). Participants had a mean number of 2.3 (1.2) dieting experiences, including Weight Watchers (43.3%), low-carbohydrate or ketogenic diet (30%), research study weight programs (13.3%), South Beach Diet (10%), measuring foods (6.7%), Nutrisystem (6.7%), Ideal Protein (6.7%), calorie counting (6.7%), Intermittent fasting (6.7%), Daniel Plan (3.3%), Paleo diet (3.3%), 21-Day Diet (3.3%), Jenny Craig (3.3%), Health Management Resources (3.3%), low-fat diet (3.3%), salad-based diet

(3.3%), no fast food (3.3%), low-caloric diet (3.3%), reduced meat consumption (3.3%), Precision Nutrition (3.3%), 4-Day Diet (3.3%), Weight Down Diet (3.3%), Glycemic Index Diet (3.3%), Trim Healthy Mama Diet (3.3%), no sugar (3.3%), and protein shakes (3.3%).

Retention

At 12-months, 22 participants (73.3%, 13 females) were enrolled in the study. Participants were considered enrolled if they continued to self-weigh and completed the exit survey. Two male and six female participants dropped out due to familial health complications (1), travel (1), loss of motivation (3), too busy (1), and lost to follow-up (2).

Anthropometrics and Weight Change

For all completing participants (n=22 for weight, a subset of n=15 for body composition), the mean percentage of body weight loss was -6.49 (8.37)% (Figure 3). From baseline to 12 months, weight significantly decreased (106.37 kg vs. 99.69 kg; mean at each timepoint; $p<0.001$). Mean BMI change was -2.33 (3.0) kg/m^2 (37.29 kg/m^2 vs. 34.96 kg/m^2; $p<0.001$) at 12 months. Cohen's d for 12-month weight changes was -0.30, indicating a small to medium effect for reducing weight.

Weight loss progress primarily occurred in the first six months of the program. From baseline to 6 months, weight significantly decreased (106.4 kg vs. 100.4 kg; $p<0.001$). Small, insignificant weight losses occurred from six to 12 months (100.4 kg vs. 99.6 kg), and 10 participants (45%) gained weight. Participants who gained weight during this period gained a mean of 2.4 (2) kg. From six to 15 months, insignificant weight loss occurred (100.4 kg vs. 100.2 kg), and 11 participants (50%) gained weight. Participants who gained weight in this period gained a mean of 3.1 (3) kg.

Two participants reached a BMI<25 kg/m^2; five participants (23%) lost >10% initial bodyweight; nine participants (41%) lost >5% initial bodyweight and were successful in

achieving clinically significant weight loss. Of the thirteen unsuccessful participants, eleven participants did not reach 5% weight loss during the 12 months. However, seven participants of those eleven participants steadily had lost weight after six months (Figure 3). Two participants had achieved 5% weight loss but regained the lost weight after six months (Figure 3).

Figure 4 revealed a large divergence in weight loss outcome at 12 months between the top-tertile and bottom-tertile groups. The top-tertile (n=7) achieved a significant weight loss from the baseline reaching -15.1 (10.0)% (p=0.003), while the bottom-tertile (n=7) lost -0.3 (2.7)% (p=0.79) (Figure 4).

Body Composition and Anthropometric Changes

Fifteen participants (68%) completed body composition and anthropometric measurements at baseline, six months, and 15 months (Table 3). No significant changes in fat mass (FM; p=0.11, six months; p=0.09, 15 months) or skeletal muscle mass (SMM; p=0.40, six months; p=0.36, 15 months) were seen from baseline to six and 15 months. SMM loss was minimal with a mean change of -1.26 (1.32) kg, and 1.21 (1.23)% bodyweight loss was due to SMM at 15 months. Weight loss due to fat mass 7.05 (7.89)% at 15 months. The overall bodyweight reduction at 15 months was -8.51 (8.01)% (n=15). Minimal reduction of SMM substantiates the safety of our dietary approach (Table 3). Waist circumference decreased significantly from baseline at 15 months (115.0 cm vs. 105.7 cm, $p<0.001$), however, hip circumference did not significantly differ at any time point (Table 3). Cohen's d for change in waist circumference at 15 months was -0.85, indicating a large effect size.

Dietary Change

Protein and fiber density significantly increased from the baseline 24-hour record (5.02 g/100 kcal and 1.41 g/100 kcal, respectively) to records two (6.39 g/100 kcal and 1.74 g/100 kcal, respectively) and three (6.05 g/100 kcal and 1.81 g/100 kcal) and four (6.05 g/100 kcal and

1.78 g/100 kcal) ($p<0.05$) (Figure 5). No further significant protein density increases were seen, however, fiber density significantly increased at record five (1.89 g/100 kcal) (Figure 5). All mean record values were within the weight maintenance box. Caloric intake, measured by kcal/kg of bodyweight, significantly decreased from baseline (18.22 kcal/kg) at records two (15.38 kcal/kg) and three (16.45 kcal/kg) ($p<0.05$) (Figure 6). No further reductions in caloric intake occurred after six months, where weight losses simultaneously slowed.

FFQs were administered at baseline and 12 months to capture habitual dietary intake (Figure 5). Protein density significantly increased (4.7 g/100kcal vs. 5.9 g/100 kcal; $p<1e-6$). Fiber density also significantly increased (1.3 g/100kcal vs. 1.6 g/100 kcal; $p<0.001$). Caloric intake, measured as kcal/kg of BW, significantly decreased from baseline to 12 months (21.9 kcal/kg vs 17.0 kcal/kg; $p<0.001$) (Figure 6). Intake of "red food items", or foods low in protein, fiber, or both, measured as kcal/kg of BW, significantly decreased from baseline to 12 months (8.1 kcal/kg vs. 3.6 kcal/kg; $p<1e-4$) (Figure 6).

Dietary Factors for Weight Loss

Protein and Fiber

Using the average of 24-hour records at multiple timepoints, fiber density was significantly correlated with percentage weight loss ($p=0.004$; Figure 7a; $n=22$). Protein density's correlation with percentage weight loss was insignificant ($p=0.06$; Figure 7b; $n=22$). However, protein density, using the FFQ, had a significant inverse correlation with energy intake from red food items (kcal/kg; $p<1e-4$; Figure 7g, h; $n=22$). Fiber density, using 24-hour records and FFQs, did not significantly correlate with measures of energy intake.

Fiber density was significantly and inversely correlated with loss of FM ($p<0.01$; Figure 7c; $n=15$). Higher protein density correlated to greater SMM loss ($p<0.05$; Figure 7d; $n=15$), which is unexpected as we hypothesized higher protein density would correlate to reduced SMM

loss. However, our sample size was small, and not all participants lost weight, weakening this statistic. Both average protein and fiber density had a significant inverse correlation with change in waist circumference ($p<0.02$; Figure 7e, f; n=15).

Protein and Fiber Type

Correlation analysis for protein types was performed using 24-hour records. On record one, the baseline weight had a significant positive correlation with the baseline TAP, calculated as a percentage of protein from TAP (mean TAP= 67.20 (18.17)%; $p=0.0396$; n=22). Baseline weight also had a significant inverse correlation with NCF intake, but not total fiber or cereal fiber intake (mean NCF intake=16.88 (9.65) g; $p=0.049$; n=22). Across all records, a significant positive relationship between fiber and TPP intake ($p<0.05$). Further correlation analysis is available in Appendix 1.

Other Factors for Weight Loss

Three Month Window

A linear regression model showed weight loss percentage at three months is predictive of 12-month weight loss percentage ($p<1e-5$; $R^2=0.68$; Figure 8), suggesting that weight loss during the first three months is crucial for long-term success.

Daily Weighing

Participants were asked to weigh daily on the provided scale. At three months, the mean number of days weighed per week was 6.55 (0.54), and at 12 months, 5.68 (0.78) (n=22). By a paired t-test, a significant difference exists between the two time points indicating participants grew less motivated to weigh daily as time increased ($p<1e-5$). Weight loss at both time points was not significantly correlated to weight loss. However, there existed a significant interaction between self-weighing and weight change ($p<1e-7$). Eleven of the 22 participants were significantly less likely to weigh if they experienced an increase in weight, indicating motivation to weigh is partially dependent on weight change.

Calculating adherence to daily weighing as the number of days weighed divided by 365 days, the mean adherence was 81.12% (0.11). Participants were divided into two halves: highest and lowest daily weighing adherence. The mean BMI of each half at zero, three, six, nine, and 12 months was insignificant. However, as shown in Figure 9, adhering to daily weighing corresponded to a greater decrease in BMI in the first year.

Session Attendance and Assignment Completion

Of the 22 sessions, the mean attendance was 19.3 (2.8) (87.6%), and of the 19 homework assignments, the mean completion was 13.6 (2.8) (71.3%). Participants not able to attend a regularly scheduled session were provided a one-on-one or small group makeup session, and an average of 2.5 (1.8) makeup sessions were given per participant (n=22) (Table 4). An insignificant inverse correlation was present between weight loss percentage at 12 months and session attendance (p=0.10; n=22). There was no trend for weight loss and homework completion.

Comparison of Cohort Success: iDip 1 versus iDip 2

iDip 1 followed a similar design as iDip 2 and has been previously described in detail [56]. Briefly, key differences were the incorporation of feedback at the end of each session and the implementation of homework assignments with feedback. There were no significant differences in male and female ratios, baseline body weights, protein density (FFQ), or fiber density (FFQ) between cohorts. Weight loss percentage at 12 months was insignificantly greater in iDip 2 (-6.49% vs. -5.35%; p=0.34). Protein and fiber density (FFQ) increased from baseline to 12 months in both cohorts; however, insignificant increases were found in comparing iDip 1 and 2 (p=0.05 protein; p=0.06 fiber).

Cost Analysis

Per person (n=22), year one costs 647.47 USD (per kilogram lost. Cost per kilogram differed substantially by weight loss success: tertile 1 (n=8, greatest weight loss at 12 months)

cost 47.35 USD, tertile 2 (n=7) 122.69 USD, and tertile 3 (n=7, least weight loss at 12 months) 1878.38 USD. Estimates of year two costs were similar to year one but did not include session delivery and had a reduced frequency of individual advising and anthropometric measurements. Per person (n=22), year two cost 326.49 USD. A detailed cost breakdown is available (Table 5). Compared to similarly successful, long-term weight management programs, such as DPP and Look AHEAD, iDip was significantly lower cost, as shown in Table 6 [57-60].

Discussion

The mean weight losses (n=22) at 12 and 15 months were -6.66%±1.77 and -6.25±1.77, respectively. Protein and fiber density increased significantly from baseline and were inversely associated with weight loss and waist circumference. Minimal loss of skeletal muscle mass occurred, indicating the safety of the approach. Long-term weight loss was predicted by weight losses in the first three months of the intervention, and there was an insignificant trend between daily weighing adherence and decline in BMI. Weight loss magnitude did not significantly increase after six months; however, there were no significant reductions in weight loss magnitude from six to 15 months, indicating sustainability of new habits and weight maintenance.

The iDip consisted of group and individual dietary education and was built upon two visual aids: the PF plot and the weekly weight chart. The PF plot provides an easy and accurate comparison of a food's nutritional value empowering participants to make informed food choices. The PF plot simplifies a weight loss diet by focusing on two key nutrients, protein and fiber, instead of calorie counting or macronutrient ratios. Uniquely, the iDip did not prescribe any strict meal plans or diet food products, nor did iDip eliminate any foods or food groups. The daily weighing and weekly weight chart served two purposes: 1) daily weighing allows for self-

monitoring of energy balance without requiring daily calorie counting of food journaling, and 2) visualizing weight progress is motivating [19].

iDip's weight loss was comparable to other intensive lifestyle intervention programs, namely the DPP and Look AHEAD programs. Cost, however, was significantly less due to critical cost-saving measures implemented: group education and no provisions of meal replacement or diet food products.

Limitations

We achieved a mean weight loss of greater than 5% initial body weight; however, the study has limitations. The sample size (n=22) was relatively small, and the success rate of achieving more than 5% weight loss at one year was 45% (n=10). Although there was an increase in the magnitude of weight loss over the previous study, it was not significant. Lastly, we did not monitor changes in health parameters such as blood lipid and glucose levels and medication changes. As iDip aims to improve obesity-associated risk factors, futures studies will include the necessary parameters.

Future Directions

iDip 2 substantiated the feasibility of our program and identified key strategies for future studies. To increase the accessibility of the program, we will move to an online platform for the third cohort. The online program will include a mobile application formulated to provide PF plots and conduct dietary assessments.

During iDip 2, we identified non-dietary barriers to weight loss, including food access, limited ability to exercise, and mental health difficulties. As such, the third cohort will have access to an advising team consisting of nutrition, social work, and medical experts.

Conclusions

iDip 2 induced significant weight loss in 45% of participants, and mean weight loss has been maintained. Weight losses were primarily from fat mass with limited reduction in muscle

mass. Substantial increases in protein and fiber density and reduction in energy intake were seen from 24-hour dietary records and the pre and post-intervention FFQ. The program relied on two key visual tools, the PF plot and weekly weight chart. It aimed to empower individuals to create a sustainable weight loss diet via group education and individual counseling. Participants understood the visual aids well, and most participants felt the program was useful and worth their time.

CHAPTER 4. MealPlot Mobile Application Development and Planned Study

Introduction

MealPlot is a mobile application developed to supplement the iDip weight loss trials. Within the project, I had the following responsibilities: design the mobile application based on research from commercial and academia developed applications, lead team meetings, and internally test the application.

Objectives and purpose

Many mobile applications related to diet and weight loss are available; however, there are significant challenges to their effectiveness. First, many utilize crowd-sourced dietary information, meaning anyone can enter nutrition facts that are then utilized by other users, which may lead to inaccurate dietary recordings. Second, many lack scientific oversight and randomized clinical trial research to demonstrate their efficacy. Third, there are several evidence-backed weight loss strategies that all have the potential to be in a mobile application: self-monitoring, goal setting, physical activity support, personalized feedback, motivational strategies, health assessment, healthy eating support, and social support [40]. MealPlot, the mobile application in development, is designed to address the following issues encountered in iDip and in currently available applications: 1) labor-intensive and error-prone processing of weight and diet data, 2) lack of on-the-go nutrition information for participants, 3) delay of personalized feedback transmission to participants, 4) limited personalized feedback and provider communication, 5) inaccuracies of nutrition data, 6) limited healthy eating support, and 7) limited health assessment tools.

The MealPlot mobile application is being developed to supplement the iDip programming and increase its weight loss efficacy by 1) providing participants with applicable dietary knowledge whenever needed, 2) streamlining communication between participant,

investigator, and healthcare providers, and 3) increasing efficiency of data collection and personalized feedback. As stated previously, mobile applications as standalone programs are limited in their efficacy unless coupled with additional intervention, such as the dietary education and individual counseling provided by the iDip program and its future sister program, EMPOWER.

Methods

MealPlot is being developed in coordination with the University of Illinois Urbana-Champaign's Applied Research Institute (ARI). Development began in October 2019 and is ongoing to add auxiliary features.

MealPlot Technical Specifications

In future EMPOWER studies, MealPlot will house identifying and protected health information, such as name and weight status. As such, it is built in a HIPAA-compliant cloud structure (Azure). All participant information is encrypted using standard encryption technologies for security purposes. MealPlot utilizes an autoscaling infrastructure model to minimize running costs without reducing performance.

MealPlot allows investigators, healthcare providers, and participants to have distinctive roles within the application. With participant consent, an investigator or healthcare provider can view all their data stored, but a participant can only view their personal data.

Participant's weight data, collected from the Withings scales utilized in iDip and now EMPOWER, is pulled into MealPlot using a publicly available API. This weight data populates a weight chart similar to that of Figure 1. The USDA dietary information database serves as the application's primary dietary data bank, and nutrition facts are pulled into MealPlot via publicly available APIs. Other dietary information is entered manually by a user or is curated by investigators. The application's architecture is detailed in Figure 10.

MealPlot Mobile Application Design

Core Features

MealPlot has three core features: Meal Planner (MP), One Day Record (ODR), and Weight Chart. MP and ODR are unique and novel features because each includes the PF plot as a form of personalized feedback and nutrition education. Like in the iDip studies, the PF plot displays protein and fiber density, two critical nutrients for safe and effective weight loss, two-dimensionally allowing for easy food comparison and meal development.

Meal Planner: MP allows users to compare foods and create and edit a meal using the PF plot. MP output for a simple meal of a sandwich and an apple is pictured in Figure 11a.

One Day Record: ODR is simply a 24-hour dietary record renamed using more patient-friendly language. Users record date, time, meal name, place prepared, and place eaten for each meal. With each meal, the user records all foods and amounts consumed. Once the user finishes food selection, the program then mimics the USDA Multiple-Pass Method by asking if the user left out any frequently forgotten foods: beverages, alcoholic beverages, sweets, snacks, fruits, vegetables, and bread. Upon recording the ODR, MealPlot displays both a PF plot and a daily energy by time chart. ODR output is pictured in Figure 11b.

Weight Chart: Utilizing a similar format as the weekly weight charts in iDip 2 (Figure 1), MealPlot displays the Weight Chart at all times. It displays participant's recorded weight from their Wi-Fi scale, goals in three-month increments, weight loss trends, and weight loss progress.

Auxiliary Features

In addition to the aforementioned core features, MealPlot allows viewing of data records, such as FFQ and body composition reports. MealPlot has several features planned or in progress.

Communication Portal: In previous iDip studies, communication between participants and providers was across Box.com, email, and phone. The communication portal will streamline communication by providing a central location for instant messaging and personalized feedback from providers.

Restaurant Food Menus: The USDA food database provides nutritional information for several restaurant food items, but it is non-specific to the restaurant. While items may be similar on the surface, their nutritional information could differ vastly.

Recipe Box: Recipe Box will store protein and fiber dense recipes that fit in the weight loss or maintenance boxes. The recipes will be curated and posted by investigators.

Planned Study Design

Testing

Throughout MealPlot's development period, the application has been extensively tested internally by both the ARI and nutrition teams. Teams tested each feature following all steps a participant would potentially complete and recording any bugs or refinements required. Upon core feature completion, which is expected in April, MealPlot will be provided to past iDip 2 participants as approved under IRB #18069. iDip 2 participants will later be asked to utilize MealPlot at their leisure, test each core feature based on a specified checklist, and submit feedback via validated quality and usability surveys: Mobile App Rating Scale (MARS) [61] and mHealth App Usability Questionnaire (MAUQ) [62]. Champaign-Urbana area dietetic students and practitioners will also be contacted to utilize MealPlot and submit feedback via the MARS and MAUQ surveys modified for providers. The quantitative feedback from both groups will be analyzed with standard descriptive statistics. Feedback will be used to improve the application, such as the addition or refinement of features.

Pilot Usage in EMPOWER

Upon core feature completion, MealPlot will be utilized in the EMPOWER clinical trial. EMPOWER is the third rendition of iDip starting in the spring of 2021. EMPOWER will consist of 19 virtual education sessions, three virtual one-on-one advising sessions with a dietetic professional, daily self-weighing via Wi-Fi scale, dietary monitoring, and MealPlot application usage. It will be a before and after study with no control group. Approximately 40 people with overweight or obesity and comorbidities will participate.

MealPlot is intended to be a supplement to the EMPOWER program. As such, it will be piloted alongside EMPOWER. EMPOWER participants will heavily use MealPlot for 1) dietary recording via scheduled ODRs, 2) daily self-weighing monitoring, 3) health assessment data from body composition and anthropometrics, 4) communication with the research team and health providers, 5) personalized feedback via PF plot and weight chart, and 6) educational tool corresponding to learning activities in virtual sessions. In addition to the required usage of MealPlot, participants will be encouraged to use the application at their leisure. Usage statistics will be gathered and correlated to weight loss and dietary improvement results.

Discussion

MealPlot development began in January 2019 and is ongoing. MealPlot aims to improve upon the shortcomings of previous dietary weight loss mobile applications and the iDip studies, namely weight and diet data collection and processing, lack of or limited personalized feedback, communication between patients and providers, the accuracy of nutritional information, and limited healthy eating support and health assessment tools. The core features of MealPlot, Meal Planner, One Day Record, and Weight Chart serve to provide immediate dietary and weight feedback, accurate nutritional information at participants' fingertips, dietary and weight goal setting, and self-monitoring of diet and weight progress. MealPlot will serve as a critical tool in

the upcoming EMPOWER study by greatly increasing participants' ability to evaluate and develop meals of their liking.

Limitations

The obvious limitation is that MealPlot is not fully developed or tested at time of writing. However, development is ongoing and while more features are slated to be added, core features are developed, fully functional, and ready to be piloted alongside EMPOWER. External testing of MealPlot, with former participants and area healthcare providers, will occur in the near future. MealPlot has been thoroughly internally tested throughout its development, as such, we expect minimal changes to be required.

Future Directions

Core feature development of the ODR and MP is completed at the time of writing. An incoming graduate student, Ashleigh Oliveira, will assist Annabelle Shaffer in the external testing of MealPlot, MealPlot and EMPOWER pilot, and auxiliary feature development. Upon Shaffer's departure in May, Oliveira will supervise the remaining portion(s) of MealPlot development. Results will be submitted for publication once MealPlot is fully developed, tested, and piloted.

Conclusions

MealPlot is a newly developed dietary weight loss mobile application. However, it is distinct from current mobile applications such as MyFitnessPal in its extensive usage of the PF plot, personalized feedback, and usage as a program supplement, not a standalone program. MealPlot is anticipated to increase dietary adherence and weight loss success in the EMPOWER study.

CHAPTER 5. Overall Conclusions and Future Directions

The iDip studies demonstrated the feasibility of the empowerment approach to weight loss, which can be defined as through education and counseling, participants experiment with food and lifestyle choices to find a diet that is both successful at inducing weight loss and sustainable for life. On average, participants lost clinically significant amounts of weight, >5% initial bodyweight, and maintained the weight losses at 18 months. Dietary improvements were significant with reductions in caloric intake and increases in protein and fiber intake.

The MealPlot application is under development with two core features completed at time of writing: meal planner and one day record. MealPlot utilizes successful components of the iDip program and builds upon them by increasing efficiency, self-monitoring, personalized feedback, and communication. Auxiliary features will be added: communication portal, fast food menus, and recipe box. MealPlot will be tested with former participants and area health providers as described in chapter 4.

The EMPOWER study will build upon the iDip study. MealPlot will be used as a tool for participant education, data collection, feedback, and self-monitoring. We anticipate MealPlot enhancing the weight loss and dietary changes of EMPOWER participants.

Tables and Figures

Table 1. Curriculum and study timeline. *Optional; **Delayed due to COVID-19 pandemic; [a]Online due to COVID-19 pandemic. All sessions, unless noted otherwise, occurred in person at Bevier Hall.

Week	Session Title	Dietary Measures	Anthropometrics	Body Composition
1	Starting Weight Loss	FFQ	X	X
2	Weight Monitoring			
3	Establishing Routine			
4	24-Hour Record Completion and Portion Sizes	24HR1		
6	Individual Advising 1			
8	Importance of Protein 1			
10	Importance of Fiber 1	24HR2		
12	Physical Activity		X	X
14	Individual Advising 2			
16	Importance of Protein 2			
18	Importance of Fiber 2	24HR3		
20	Trouble Shooting for Slow Weight Loss			
22	Peer Experience Sharing and Discussion			
24	Difference Between Weight Loss and Weight Maintenance	24HR4	X	X
26	Building a Healthy Plate			
28	"Diet" and Replacement Foods			
32	Barriers to Healthy Eating			
36	Fats	24HR5		
39	Individual Advising 3			
44	Salt	24HR6 with sodium content		
	*The Science of Setting Yourself Up for a Successful Weight Loss Journey by Janet Liechty, PhD, LCSW			
48	Eat the Rainbow: The Importance of Vitamins and Minerals			
	*Staying Motived for a Successful Weight Loss Journey by Janet Liechty, PhD, LCSW			

Table 1 (cont.)

51	No Session.		Delayed to 15-month.**	Delayed to 15-month.**
52	[a]Exit Session	FFQ		
53-104	Follow-up period	Daily weighing with all other measures done on an as-needed basis.		

Table 2. Characteristics of participants at baseline (n=30).

	Total (n=30)
Sex	**Number (%)**
Male	11 (36.7)
Female	19 (63.3)
Age	**Number (%)**
18-29	1 (3.3)
30-49	16 (53.3)
50-64	10 (33.3)
64+	3 (10.0)
Mean Age	49.3 (SD=11.7)
Education	**Number (%)**
High school	8 (26.7)
Bachelor's degree	8 (26.7)
Graduate degree	13 (43.3)
Unknown	1 (3.3)
Ethnicity	**Number (%)**
White	25 (83.3)
Black or African American	4 (13.3)
Asian	1 (3.3)
BMI	
Mean BMI	37.3 (SD=6.1)
Previous weight loss attempts	
Mean attempts	2.3 (SD=1.2)

Table 3. Weight and BMI (n=22) and anthropometrics and body composition (n=15) data from baseline to 12 or 15-months. *Significant change from baseline, p<0.05. **Measurements delayed to 15-months due to the COVID-19 pandemic.

	Baseline (SD)	**6-months (SD)**	**12-months (SD)**	**15-months (SD)**
N=22, all completing participants				
BMI	37.29 (6.1)	35.22 (6.7)*	34.96 (7.1)*	35.13 (7.4)*
Weight (kg)	106.37 (21.6)	100.44 (22.4)*	99.69 (23.2)*	100.13 (23.7)*
Weight Loss (%)	N/A	¯ 5.73% (6.3)	¯ 6.49% (8.4)	¯ 6.15% (8.2)
N=15, participants with body composition measures				
BMI	34.97 (5.1)	32.31 (5.3)*	31.84 (5.6)*	31.99 (5.6)*
Weight (kg)	101.42 (20.9)	93.85 (21.6)*	92.55 (22.4)*	92.94 (22.1)*
Weight Loss (%)	N/A	¯ 7.59% (6.7)	¯ 8.91% (8.9)	¯ 8.51% (8.0)
Waist Circumference	114.99 (11.9)	107.90 (15.1)	**	105.74 (12.6)*
Waist:Hip Ratio	0.94 (0.07)	0.92 (0.09)	**	0.91 (0.02)*
Female (n=7)	0.88 (0.06)	0.86 (0.06)	**	0.86 (0.02)
Male (n=8)	0.94 (0.07)	0.92 (0.09)	**	0.91 (0.07)*
Fat Mass (kg)	42.12 (13.9)	35.59 (14.7)	**	34.84 (14.5)
Weight Loss due to Fat Mass	N/A	¯ 7.15% (5.6)	**	¯ 7.05% (7.9)
Skeletal Muscle Mass (kg)	33.86 (9.5)	32.91 (9.6)	**	32.68 (8.8)
Weight Loss due to Skeletal Muscle Mass	N/A	¯ 0.78% (0.9)	**	¯ 1.21% (1.2)

Table 4. Session attendance, makeup sessions, and homework completed by participants in year one.

	Number Given	Mean Attendance or Completion/Person (SD) (N=22)	Sessions Attended as Makeups (%)
Regular Session Attendance	22	19.27 (2.8)	
Makeup Sessions	55	2.5 (1.8)	12.97
Homework Given	19	13.54 (2.8)	

Table 5. Detailed cost breakdown of the iDip 2 program (n=22).

	Total Hours	Cost, 29.97 USD/hour	
Year 1 (Y1)			
Session Delivery	85.5	$	2,562.44
Individual Advising	49.5	$	1,483.52
Weight Chart & Weekly Communication	190.7	$	5,715.28
24-hour & FFQ Measurements	88	$	2,637.36
Body Measurements	16.5	$	494.51
Summary Reports	16.5	$	494.51
	Total Labor Cost, Y1	$	13,387.60
	Labor Cost + Scale Cost, Y1	$	14,838.39
	Cost per Person, Y1	$	674.47
	Cost per Kg Lost	$	148.09
	Cost per Kg Lost *Top tertile*	$	42.72
	Cost per Kg Lost *Bottom tertile*	$	1,878.38
Year 2 (Y2)			
Individual Advising	27	$	809.19
Weight Chart & Weekly Communication	190.7	$	5,715.28
FFQ Measurement	11	$	329.67
Body Measurements	11	$	329.67
Summary Reports	11	$	329.67
	Total Cost, Y2	$	7,513.48
	Cost per Person, Y2	$	341.52
	Total Program Cost	$	22,351.87
	Cost per Person	$	1,015.99

Table 6. Cost comparison, in 2020 USD, of iDip 2, DPP, and Look AHEAD programs. *Insignificant differences in 12-month weight loss percentage across studies.

	iDip 2*	Diabetes Prevention Program*	Look AHEAD*
Per Person (Y1)	674.47	2173.9	3260.25
Per Person (Y2)	341.52	1057.19	2212.5
Per Kg Lost (Y1)	148.09	310.56	376.59
Total Cost (Y1-2)	1015.99	3231.09	5472.75

Figure 1. Weekly weight chart provided to participants via paper (year one) or electronically (year two). Blue line: daily weight in kilograms; green line: weight goals provided in three-month increments of 6 kg each (-1 lb/week); red line: goal weight loss trendline (-0.45 kg/week, -1 lb/week); dotted blue line: linear trendline of daily weights.

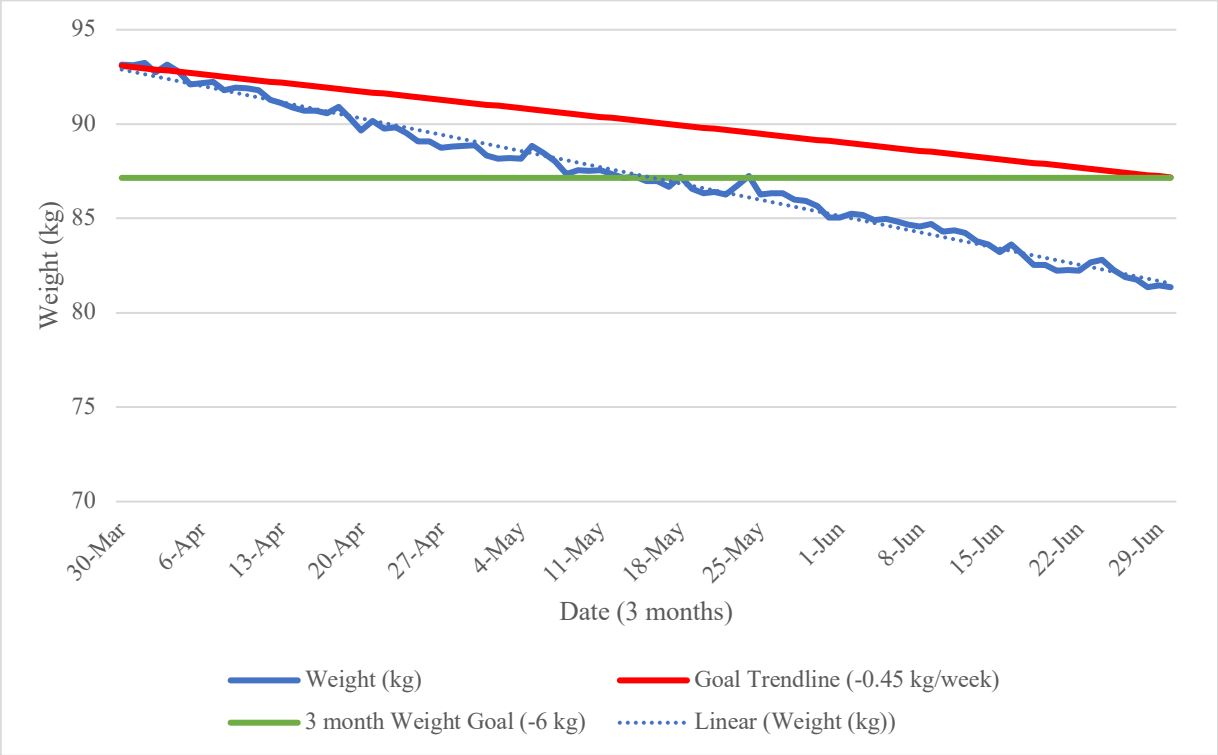


Figure 2. The protein-fiber (PF) plot served as the primary dietary feedback mechanism for participants. Fiber density is displayed on the horizontal axis, protein density on the vertical axis. Blue box: the nutrient target for weight maintenance (1.4-2.8 g/100kcal fiber, 4-8 g/100kcal protein); green box: the nutrient target for weight loss (1.8-3.2 g/100kcal fiber, 7-11 g/100kcal protein); green dots: foods very dense in fiber, >1.8 g/100kcal, or protein, >7 g/100kcal; yellow dots: foods somewhat dense in fiber, 1.4-1.8 g/100kcal, or protein, 4-8 g/100kcal; red dots: foods low in fiber, <1.4 g/100kcal, or protein, <4 g/100kcal; blue dot: the combined total of all foods consumed.

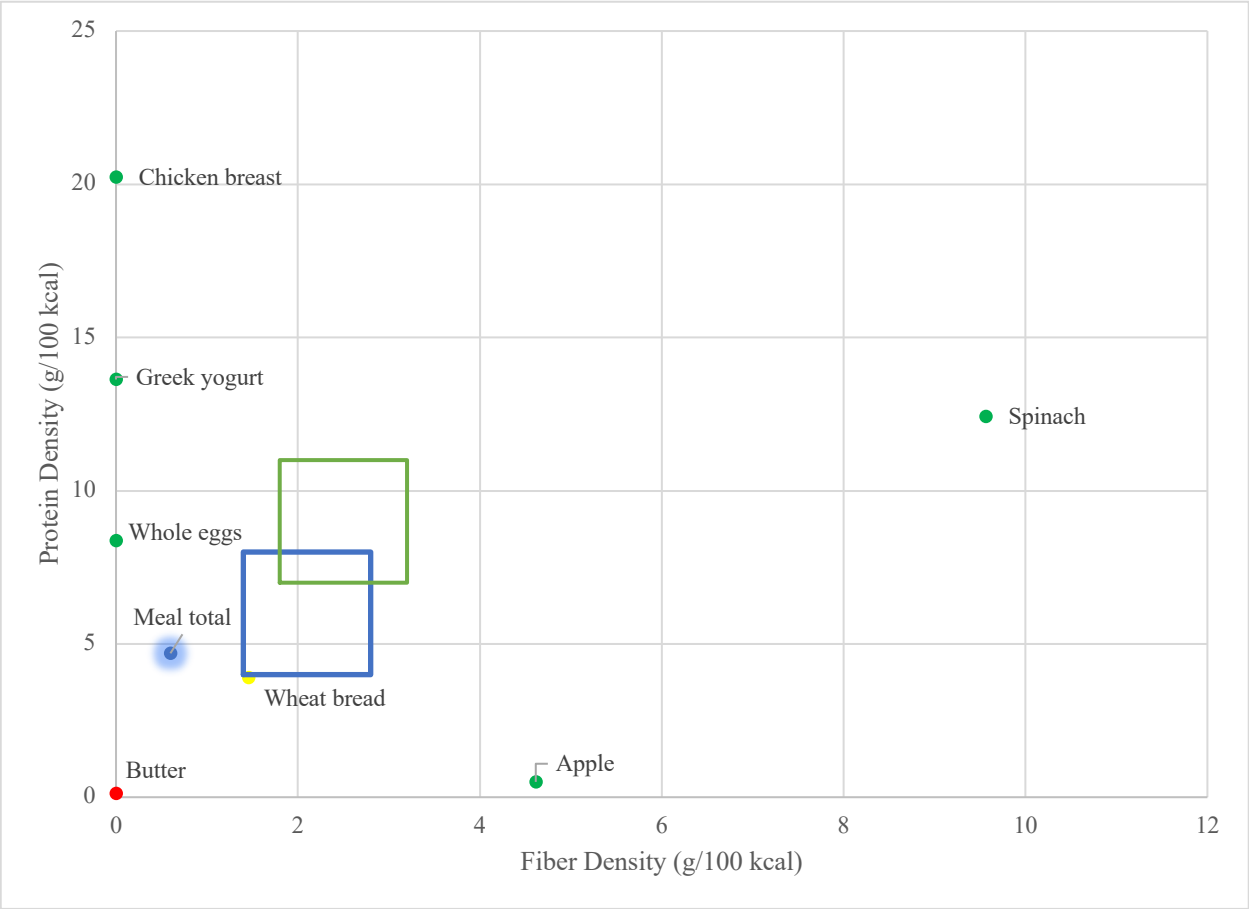


Figure 3. Weight loss percentage from baseline by individuals (#1-22) at six months (blue), 12 months (orange), and 15 months (gray). Mean weight at each time point is shown in the far right set of bars (#23).

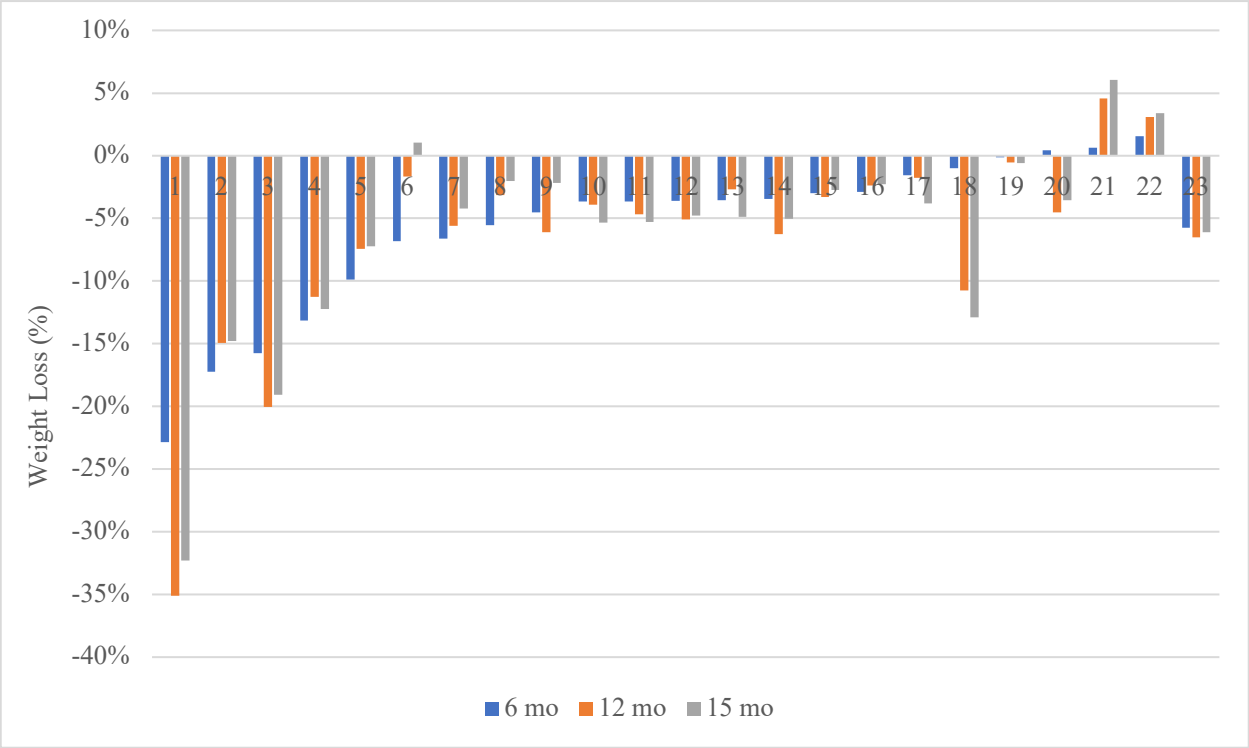


Figure 4. Weight loss percentage from baseline for all participants at 12-months (n=22). Participants were divided into tertiles based on 12-month weight loss percentages. Blue line: mean weight loss of all participants; orange line: mean loss of the top seven performers; gray line: middle eight; yellow line: bottom seven.

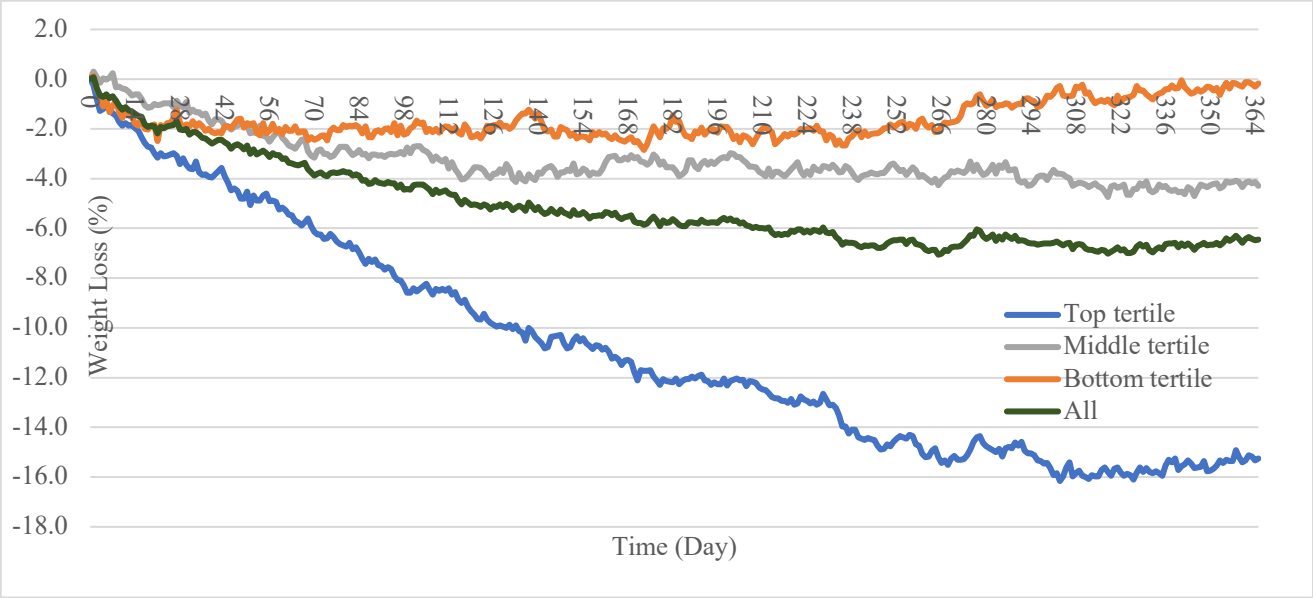


Figure 5. Mean protein and fiber density of 24-hour dietary records submitted bi-monthly in year one (blue dots) and baseline and 12 month FFQ (yellow diamonds). *Significant difference from baseline in protein density, $p<0.05$. §Significant difference in fiber density, $p<0.05$.

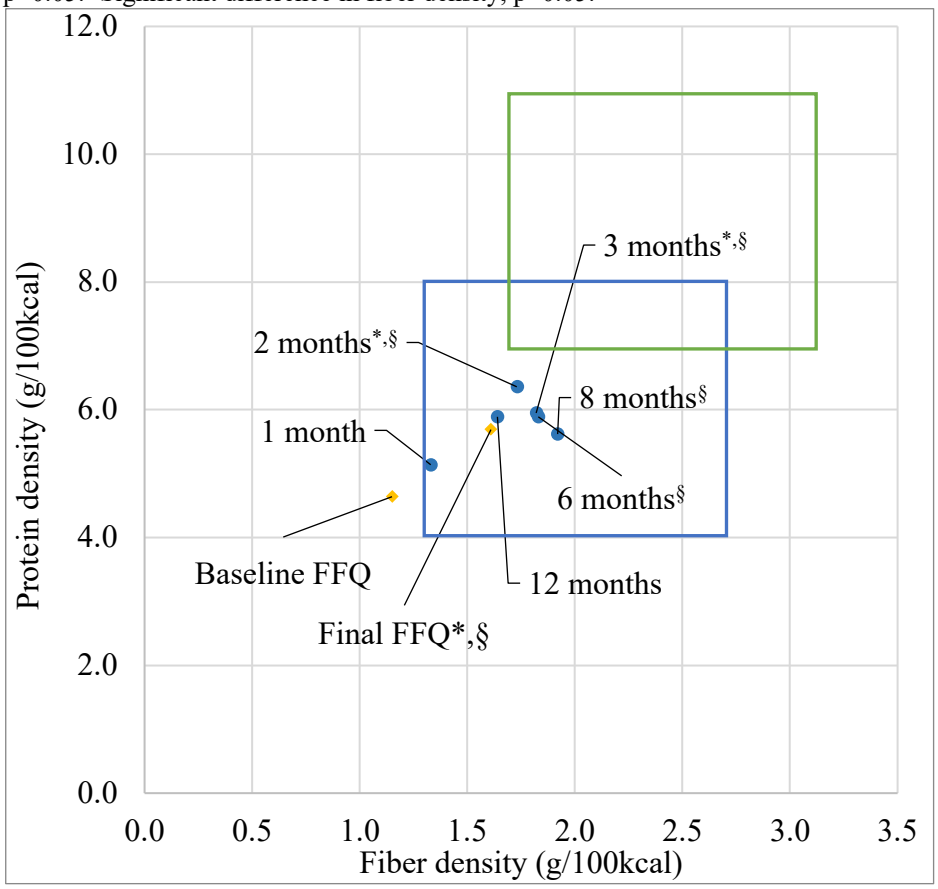


Figure 6. Total caloric intake and caloric intake from red foods measured by 24-hour dietary records (R1-6) and FFQs. All measures provided as kcal/kg of bodyweight at the time of the record. Orange line, total caloric intake measured by FFQ; blue line, total caloric intake measured by 24-hour dietary records; red line, caloric intake of red foods measured by FFQ.

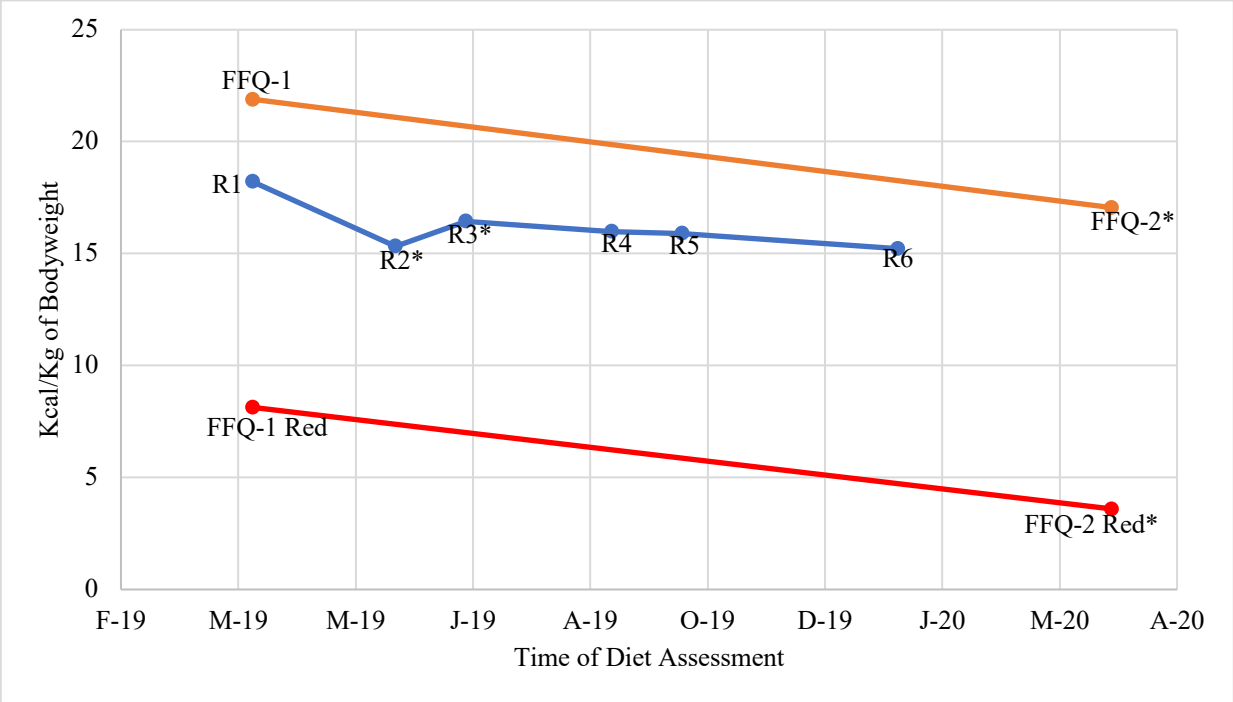


Figure 7. A-F are correlations relating anthropometrics to the average nutrient density of six bi-monthly 24-hour records. G-H are correlations between protein density, measured by FFQ, at baseline and 12 months and intake of red calories. A, B, G, H, n=22; B-F, n=15.

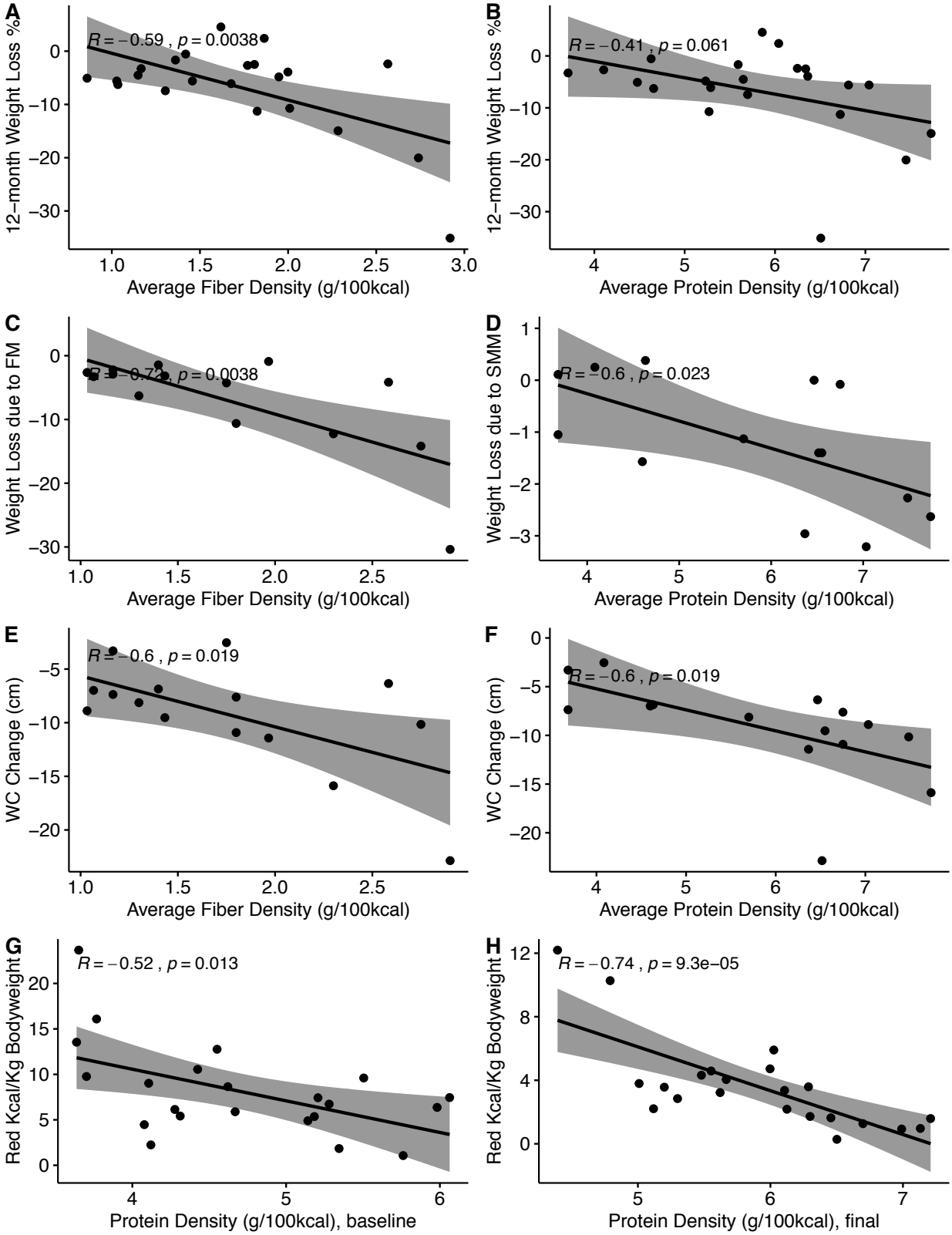


Figure 8. Weight loss during the first three months was strongly predictive of weight loss at 12-months ($p<1e-5$; $R^2=0.68$).

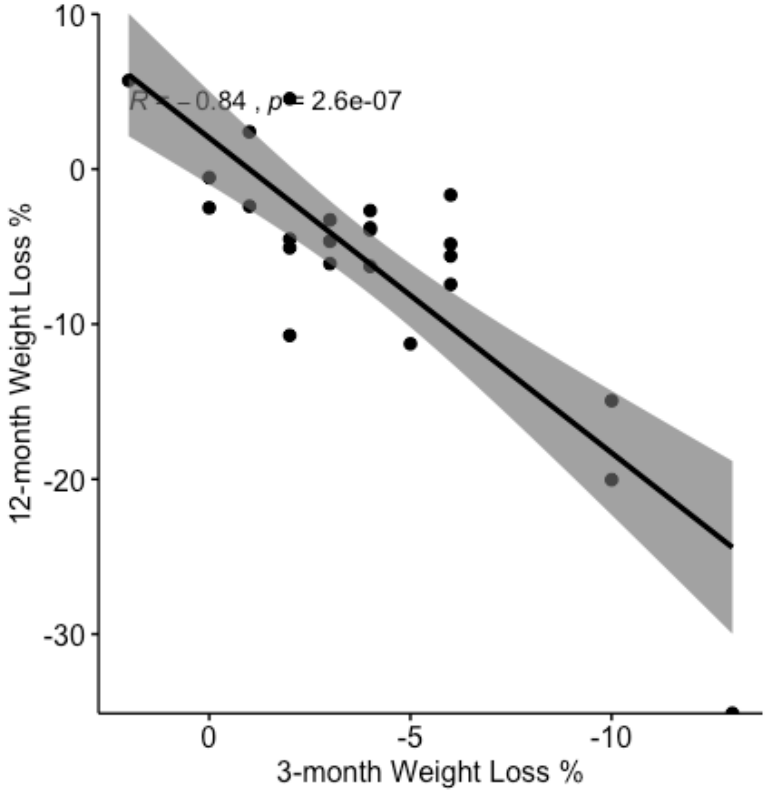


Figure 9. Comparison of high (orange) and low (blue) daily weighing groups in body mass index change over 12 months.

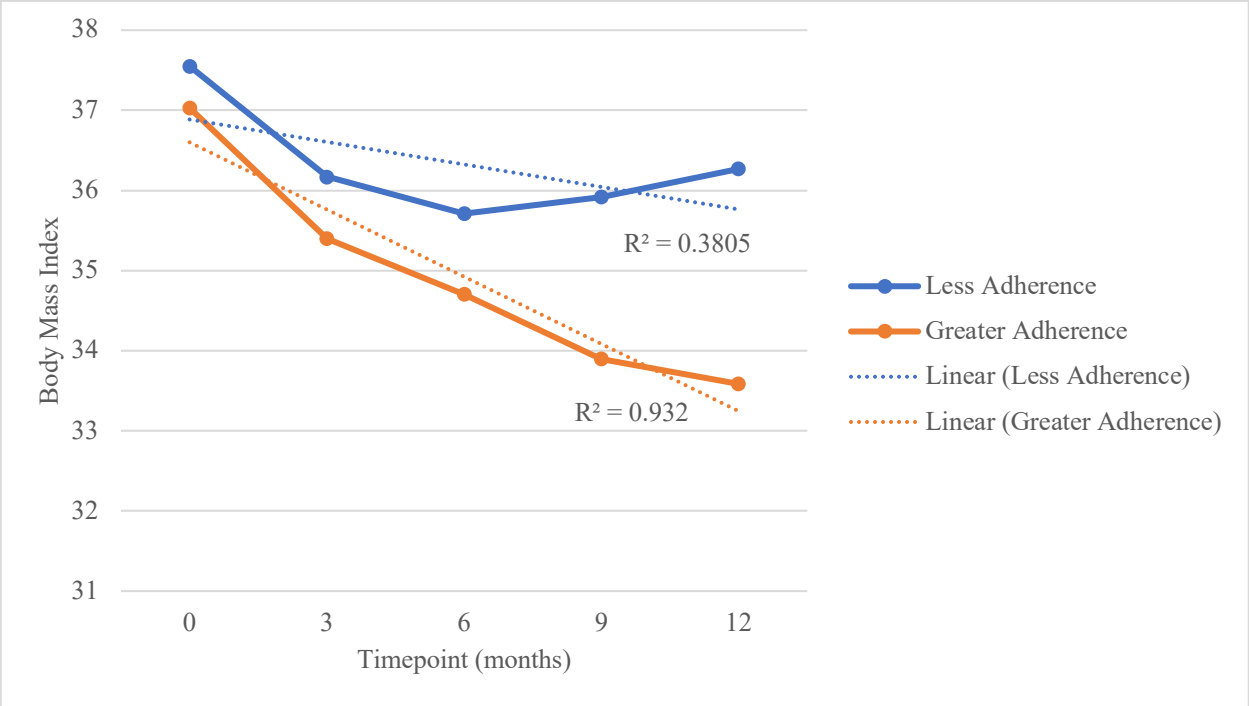


Figure 10. MealPlot mobile application architecture. Green arrows indicate information input to the application; blue arrows indicate information output.

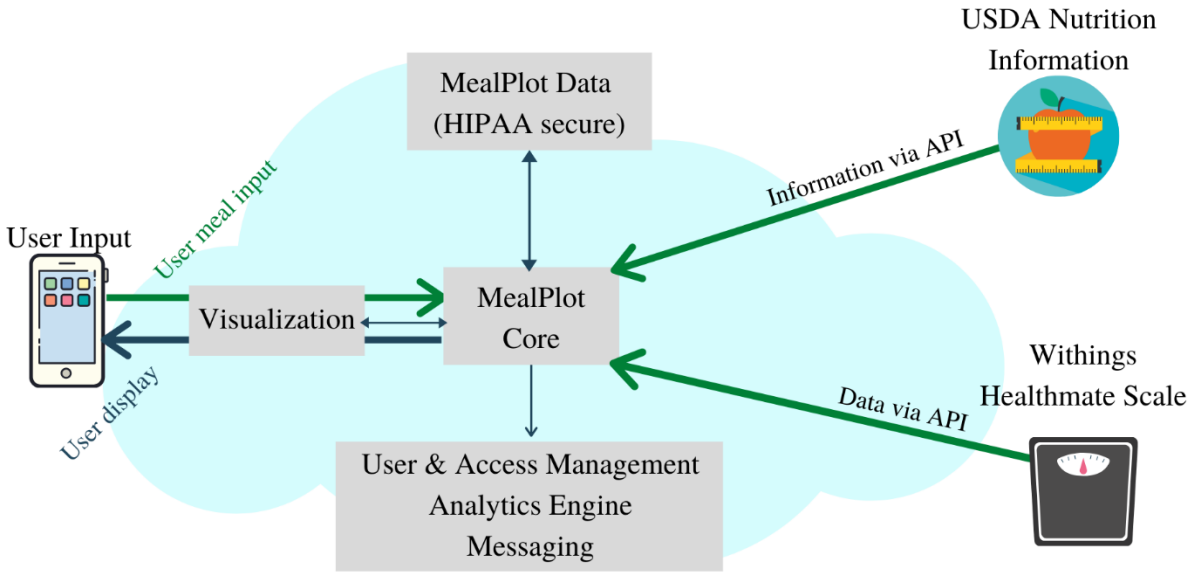
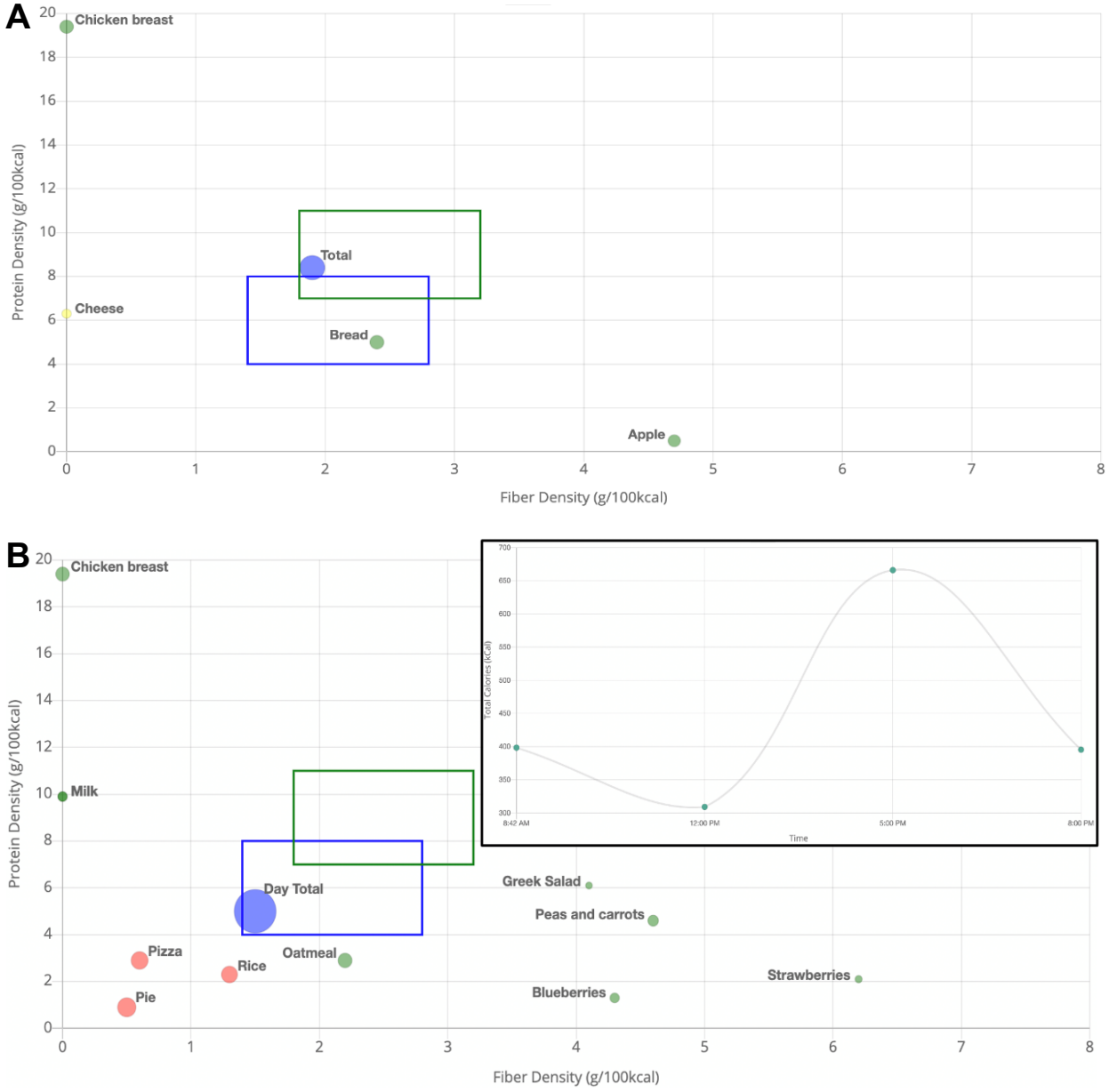


Figure 11. A shows the Meal Planner; B displays One Day Record; insert of B displays an alternate view of energy intake in One Day Record.



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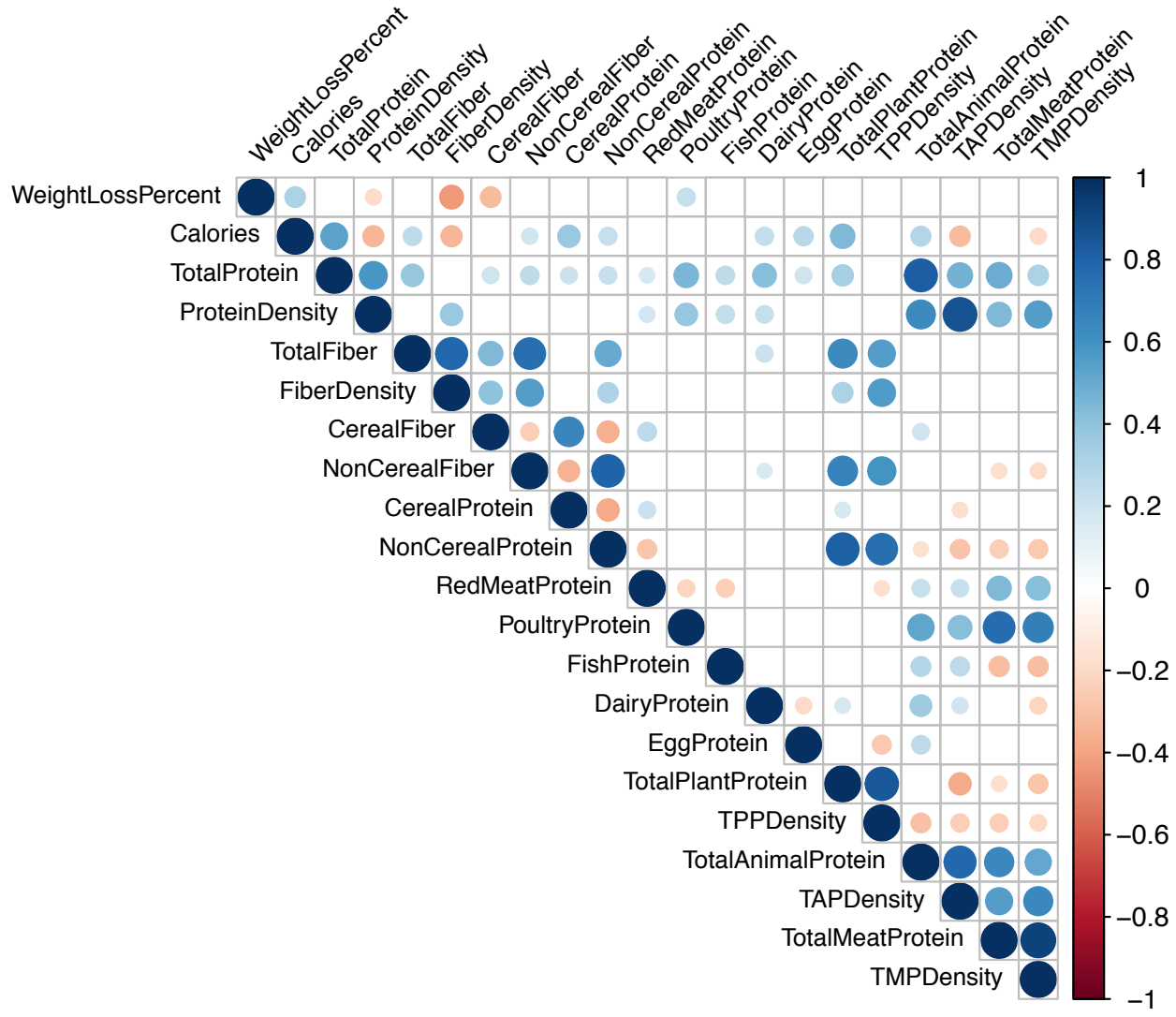
Appendix A. Protein and Fiber Type Analysis



Correlation analysis of all 24-hour records. Significant correlations are identified by colored circle ($p<0.05$); insignificant correlations are blank; small circle size indicates a larger p-value. Blue indicates a positive correlation and red indicates a negative correlation.