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The Acute Effects of a DASH diet and Whole Food, Plant-Based diet on Insulin Requirements and Related Cardiometabolic Markers in Individuals with Insulin-Treated Type 2 Diabetes

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Abstract

Aims: There is limited research regarding insulin dosing changes following adoption of plant-based diets. We conducted a nonrandomized crossover trial utilizing two plant-based diets (Dietary Approaches to Stop Hypertension, or DASH, and Whole Food, Plant-Based, or WFPB) to assess acute changes in insulin requirements and associated markers among individuals with insulin-treated type 2 diabetes.

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Contribution Statement

TMC, EKC, KV, JA, and SDW participated in the conceptualization of the study. TMC, EKC, JA, TM, LB, NW participated in the study investigation and TMC, EKC, and LB participated in project administration. KHC provided resources. EKC, NW, KHC, TF, and LB participated in data curation and DP and DKH provided formal analysis. TMC, EKC, and SDW provided supervision. TMC wrote the original draft of the manuscript and all co-authors participated in review and editing.

Declaration of Competing Interest

TMC receives royalties from general interest books about plant-based nutrition (Benbella Books and Penguin Random House). In addition, he has received income from a medical practice focused on lifestyle medicine (Thomas Campbell, MD PLLC). EKC has no conflicts other than those of her spouse (TMC). SDW has received consulting honoraria from Medtronic Diabetes and Ascencia Diabetes. None of the other authors declare any conflicts.

Methods: Participants (n=15) enrolled in a 4-week trial with sequential, one-week phases: Baseline, DASH 1, WFPB, and DASH 2. Each diet was ad libitum and meals were provided.

Results: Compared to baseline, daily insulin usage was 24%, 39%, and 30% lower after DASH 1, WFPB, and DASH 2 weeks respectively (all $p < 0.01$). Insulin resistance (HOMA-IR) was 49% lower ($p < 0.01$) and the insulin sensitivity index was 38% higher ($p < 0.01$) at the end of the WFPB week before regressing toward baseline during DASH 2. Total, LDL, and HDL cholesterol, leptin, urinary glucose, and hsCRP decreased to a nadir at the end of the WFPB week before increasing during DASH 2.

Conclusions: Adopting a DASH or WFPB diet can result in significant, rapid changes in insulin requirements, insulin sensitivity, and related markers among individuals with insulin-treated type 2 diabetes, with larger dietary changes producing larger benefits.

Keywords

DASH Diet; Insulin Resistance; Medical Nutrition Therapy; Plant-Based Diet; Type 2 Diabetes Mellitus; Vegan Diet

1.0 Introduction

Obesity prevalence has increased in recent decades[1] and now 14.7% of American adults have diabetes[2]. Type 2 diabetes accounts for 90-95% of total cases. Improving dietary habits is an integral part of disease self-management and is recognized by the American Diabetes Association as offering benefits for glycemic control, weight control and other risk factor management[3]. The Dietary Guidelines for Americans 2020-2025[4] recommends a healthy dietary pattern across the lifespan and describes three dietary patterns as examples: A “Healthy US-style” dietary pattern, a “Mediterranean” dietary pattern, and a “Vegetarian” dietary pattern.

These plant-enriched, or plant-based, dietary patterns are all richer in fruits, vegetables, legumes, and whole grains and lower in processed foods, saturated fat, added sugar, and salt, than typical American diets. A moderately plant-based approach is the Dietary Approaches to Stop Hypertension (DASH) diet, a “healthy US-style” diet where no food choice is eliminated but instead the emphasis is on consuming more fruits, vegetables, whole grains and low-fat dairy, and reducing saturated fats, sugar and salt. At the ‘end’ of the plant-based dietary spectrum is a whole-foods, plant-based (WFPB) diet comprised of beans, whole grains, fruits and vegetables that minimizes or fully excludes animal foods, added fats, and most added sugars.

Both the DASH and WFPB diets have been shown to lower blood pressure[5, 6], cholesterol[7, 8], weight[9], and blood sugar[10, 11]. Treatment programs integrating a WFPB diet have been shown to lead to atherosclerotic regression, improvement in angina, and reduced risk of cardiac events among people with diagnosed coronary artery disease[12, 13]. These benefits beyond glycemic control are particularly important in type 2 diabetes. According to 2015-2018 NHANES survey, only 21% of people with diabetes achieved control of their combined risk factors of blood sugar, cholesterol, and blood pressure[14].

If dietary factors change quickly, then metabolism, and specifically glycemic control, also changes quickly. Within hours, intralipid infusions increase intramyocellular lipid and reduce glucose disposal by up to 40% during hyperinsulinemic-euglycemic clamp procedure[15, 16]. Similarly, a high fat diet consumed for just three days can increase intramyocellular lipid levels and result in a 17% reduction in glucose infusion rate during clamp procedure[15]. Conversely, six days of a very low-calorie diet has been shown to significantly reduce intramyocellular lipid, increase glucose disposal rate and decrease insulin resistance[17].

Despite knowing that large dietary changes can have rapid effects, there is limited guidance regarding acute changes in insulin requirements among insulin-requiring individuals with type 2 diabetes[18] in response to dietary intervention. This is problematic because up to 24% of Americans with type 2 diabetes require insulin therapy[19] and nutrition management, as part of diabetes selfmanagement, is recommended for all patients with diabetes. Given the prevalence of patients with insulin-requiring type 2 diabetes and the hope that they might improve outcomes by adopting dietary change, this is an important gap in the literature.

Given this background, we conducted a nonrandomized crossover study of individuals with insulin-treated type 2 diabetes and a BMI of 27 or greater, using a DASH diet and a WFPB diet, to better characterize the acute effects of these plant-based interventions on total daily insulin requirements and, secondarily, to describe changes in related cardiometabolic and obesity biomarkers.

2.0 Methods

2.1 Participants and Study Design

Participants were recruited from the University of Rochester endocrinology clinic. Inclusion criteria included: being over the age of 18, having type 2 diabetes requiring daily insulin, having a body mass index (BMI) of at least 27kg/m^2, and a hemoglobin A1c (HbA1c) between 6.5 - 9.5% (48 and 80 mmol/mol). English fluency was required. Exclusion criteria included diagnosis of type 1 diabetes or latent autoimmune diabetes in adulthood, use of insulin pump, or medical conditions presenting confounders or potential risks related to dietary change, including recent estimated glomerular filtration rate of 45 mL/min/1.73 m^2 or lower, recent hyperkalemia, pregnancy, liver cirrhosis, or active malabsorption disorder. Individuals taking the following medications were excluded: warfarin, aspirin (if >500mg daily), vitamin C (if >1000mg daily), antipsychotics, systemic glucocorticoids within three months, phentermine, orlistat, lorcaserin, phentermine/topiramate or bupropion/naloxone in the past three months, sulfonylureas or glinides in the past three months. If used, the dose of metformin, GLP-1 agonist, or SGLT2 inhibitor had to be stable over the past three months prior to the study, and the participant's dose of insulin had to be stable over the past three months (no changes in their prescription of > 10%). Individuals with illicit drug use (not including marijuana), high risk alcohol use, food allergies interfering with study adherence, or recent vegan or vegetarian diet were also excluded.

After consent, participants attended a baseline visit where a 14-day continuous glucose monitor (iCGM), Freestyle Libre Pro, was placed on their upper arm, baseline questionnaires were completed, and they were provided with food and insulin diaries as well as glucose tablets and instructions on how to use them in case of non-emergent hypoglycemia. To avoid unanticipated behavioral adjustments, participants were unable to access results from the CGM and were asked to continue their baseline routine of checking blood glucose. After seven days on their normal baseline diet, they came to the University of Rochester Medical Center research clinic between 7AM and 9AM, in a fasted state, where they underwent a 2-hour oral glucose tolerance test (OGTT) with blood drawn at time 0, 60 and 120 minutes. They were instructed to withhold all of their morning diabetes medication, including insulin, until after the testing was completed. Immediately following the baseline OGTT they started a DASH diet for seven days (DASH 1). At the end of this DASH 1 week, they completed the same OGTT testing, a new continuous glucose monitor was placed, and then they started a WFPB diet for 7 days. They completed the same OGTT testing at the end of the WFPB diet week, and then completed a second week of the DASH diet with repeat testing at the end (DASH 2) (Figure 1).

As a safety measure, participants were contacted daily by a study physician after they started study food in order to monitor blood sugar and adjust insulin as needed to prevent hypoglycemia. In anticipation of lower blood glucose levels, the night before the first DASH week and again the night before starting the WFPB week, basal insulin doses were reduced by approximately 20%. Prandial dose regimens were also adjusted downward by 10-20% at the start of DASH 1 and WFPB weeks, however the adjustment was individualized. After the initial adjustments, insulin doses were adjusted to a target of normal or near normal blood glucose levels, with allowance for individual variation.

Participants were instructed to eat as often and as much as they wanted to be comfortably full. Snacks and three prepared meals a day were provided in order to enhance adherence to the study diet, but participants were encouraged to consume their own food in place of, or in addition to, the provided food, as long as their food was ‘on plan’. To ensure a consistent provision of food throughout the study, the provided food consisted of approximately 1800 calories per day. The DASH diet was based on the dietary pattern described by the National Heart, Lung, and Blood Institute[20], emphasizing increased fruits, vegetables, whole grains, and low-fat dairy while including fish, poultry, and some vegetable oils. Foods higher in saturated fat, including red meats, full fat dairy, and solid fats were limited, as were foods high in added sugar and sodium. The ad libitum WFPB diet consisted of fruits, vegetables, whole grains, legumes, potatoes, nuts and seeds. The WFPB diet fully excluded all animal products and all added oils/solid fats. The study was reviewed and approved by the University of Rochester Research Subjects Review Board and registered on clinicaltrials.gov (NCT04048642).

2.2 Study Outcomes

Participants recorded and reported daily insulin usage. Blood glucose was tracked by a Freestyle Libre Pro continuous glucose monitor throughout the study, but both study participants and physicians were blinded to the CGM readings during the intervention.

Study physicians used participants' regular blood glucose tracking results to adjust insulin. Freestyle Libre Pro data are reported here. At each weekly clinic visit participants were assessed for weight, blood pressure, and resting heart rate. Weight was measured in a fasting state in the morning, in light clothing, without shoes, and blood pressure was assessed by an automated blood pressure cuff taken after 5 minutes of rest. Resting heart rate was assessed by the blood pressure cuff during the blood pressure assessment. In addition, a urine sample was collected to assess urinary glucose. After weight and blood pressure, the participant had a blood draw, considered time 0, and then consumed 75g of glucose in a standard glucose tolerance beverage within 5 minutes.

The baseline blood draw included a lipid panel, high sensitivity C-reactive protein, glucose, insulin, and C-peptide, which were sent to the University of Rochester Medical Center's CLIA-certified clinical laboratory and assessed using standard methods. Separately, blood samples to measure leptin and adiponectin were collected in serum separator tubes and centrifuged at 1300 RCF for 10 minutes in a swinging bucket centrifuge (Thermo Scientific) to separate plasma. The plasma was transferred to new tubes and stored at −80°C in an ultra-low temperature freezer until their analysis. Leptin and total adiponectin levels were measured in these samples using ELISA kits (11-LEPHU-E01 and 80-ADPHU-E01, ALPCO) per the manufacturer's instructions. Absorbance was measured using a microplate spectrophotometer (BioTek).

At 60 minutes and 120 minutes following the first blood draw, another blood sample was collected to measure insulin, glucose, and C-peptide to complete the OGTT. This testing process was repeated 4 times, at the end of each study phase. Insulin sensitivity was assessed by HOMA-IR ((Fasting insulin, uIU/mL) x (Fasting glucose,mg/dL)/405) and the insulin sensitivity index (ISI) was calculated from the OGTT results by using a modified Matsuda index (ISI = k/sqrt(G_0 x I_0 x G_{120} x I_{120}) where k = 10,000, G_0 and G_{120} are plasma glucose concentrations at 0 and 120 min, I_0 and I_{120} are plasma insulin concentrations at 0 and 120 min)[21, 22]. Participants completed a 3-day food diary every week, starting with the baseline diet, and these were reviewed and analyzed by a dietitian using Nutrition Data System for Research, version 2017.

2.3 Statistical Methods

The study was 80% powered to detect a 20% difference in the insulin requirements between DASH and the plant-based diet using a 2-sided 0.05 level test. Distributions of baseline characteristics were summarized via means and standard deviations (SD) for continuous variables and counts and proportions for categorical variables. Since most readers are more familiar with the usual arithmetic mean as a summary of total daily insulin dose, while it is arguably better linearly modeled on the log scale and thus summarized via its geometric mean (which is generally smaller), both arithmetic and geometric mean total daily insulin dose appear in Table 1. All p-values are two-sided.

Linear mixed effects models were used to model each dietary intake outcome as a function of a fixed effect for diet (Baseline, DASH 1, WFPB, DASH 2) with a random effect for subject to account for longitudinal dependence, given that each subject was sequentially placed on each diet. Results were summarized via diet-specific (arithmetic) means and

their differences, along with 95% confidence intervals (CI) and p-values for mean changes. Missing data was handled automatically by the linear mixed effects models, under the common Missing At Random (MAR) assumption.

Insulin, blood glucose, and cardiometabolic outcomes were all log-transformed to symmetrize distributions prior to fitting similar linear mixed effects models with a fixed effect of diet and a random subject effect. Diet-specific means and their pairwise differences on the log scale were exponentiated and reported as geometric means and ratios thereof, along with 95% CI and p-values.

Individual trajectories of total insulin usage by day, relative to the insulin dose at the end of the baseline week were used to visualize subject-specific relative changes in total insulin, with the geometric mean overlaid to highlight trends. The first day of each diet was omitted due to non-dietary influence of the OGTT.

3.0 Results

From October 2020 to January 2022, 225 individuals were screened, out of which 117 were eligible (Figure 2). 15 participants were enrolled, and 12 participants completed all visits. Three participants withdrew after their baseline visit, including one who was scheduled unexpectedly for surgery for an unrelated, pre-existing orthopedic problem, one who was in a motor vehicle accident prior to starting the intervention, and one who started new employment and could not continue the weekly assessments.

Baseline characteristics of the 15 participants who enrolled are shown in Table 1. Participants had diagnosed diabetes for an average of 12 years and their most recent HbA1c was 8.4% (68 mmol/mol). On average, participants took 90.1 units of insulin a day, with a range of 34 units/day to 205 units/day.

3.1 Dietary changes

3-day food diaries showed large changes in nutrient intakes during each dietary phase (Table 2, Figure 3). Total calories were lower during all three dietary phases compared to baseline ($p<0.01$ for all), though calorie intake during each dietary phase was not significantly different from other dietary phases ($p>0.25$ for all). The DASH diet had less total fat ($p<0.01$) and saturated fat ($p<0.01$), and more fiber ($p<0.01$) than the baseline diet. Protein intake was significantly higher only during DASH 1 ($p<0.01$). The WFPB diet was significantly lower in total and saturated fat and protein than baseline and both DASH weeks ($p<0.01$ for all). The WFPB diet was higher in fiber and carbohydrate ($p<0.01$ for both). There were no significant differences in nutrient intake between DASH 1 and DASH 2 ($p>0.18$ for all comparisons).

3.2 Insulin Changes

By the end of the DASH 1 phase, total daily insulin requirements had dropped 24% ($p<0.01$) compared to baseline (Table 3 and Figure 4). By the end of the WFPB phase, total daily insulin requirements had dropped 39% ($p<0.01$) compared to baseline. Upon resumption of

the DASH diet, insulin dosing increased 15% from the end of the WFPB week, though the difference between WFPB and DASH 2 was not statistically significant (p=0.07).

Average daily blood sugar was 22-24% lower across dietary phases compared to baseline (p<0.01 for all, Table 3). The WFPB resulted in the lowest fasting blood sugar, which was significant when compared to baseline (p<0.01), DASH 1 (p<0.01), and DASH 2 (p=0.01).

HOMA-IR decreased by 30.0% during DASH 1 (p<0.01, Table 3) and 49% during the WFPB diet (p<0.01). HOMA-IR subsequently increased during DASH 2 but remained 28% lower than baseline (p=0.02). The insulin sensitivity index was 17% higher at the end of the first DASH diet (p=0.14) and was 38% higher at the end of the WFPB diet (p<0.01), but decreased to near baseline by the end of DASH 2. Urinary glucose decreased across all three phases (p<0.01 for all).

3.3 Cardiometabolic Markers

Weight decreased during each dietary phase, with a 3% lower weight at the end of the third week compared to baseline (p <0.01, Table 4). Total, HDL, and LDL cholesterol all reached their nadir at the end of the WFPB week and total and LDL cholesterol significantly increased upon returning to the DASH diet (p<0.01 for both). Systolic and diastolic blood pressure did not significantly change after DASH 1 or WFPB compared to baseline, but systolic BP was lower after DASH 2 (p<0.01). hsCRP was lower during all three dietary phases compared to baseline, but only significantly so at its nadir after the WFPB week (42% reduction, p=0.01).

There were very few adverse events. One participant had a robust blood sugar response and had 3 episodes of hypoglycemia that resolved with snacks and/or glucose tablets at home.

3.4 Adipokines

Leptin was lower during all three dietary phases compared to baseline, but only significantly so at its nadir after the WFPB week (28% reduction, p=0.03), before rebounding at the end of DASH 2. There was insufficient evidence of any changes in Adiponectin (p > 0.15 for all).

4.0 Discussion

Both a DASH diet and WFPB diet, consumed without mandated calorie or portion restriction, result in large, rapid reductions in insulin requirements among community dwelling participants with insulin-treated type 2 diabetes. Within two weeks, participants were taking 39% less insulin while maintaining significantly lower blood glucose. Simultaneously, significant cardiometabolic improvements were observed in total and LDL cholesterol, leptin, weight, and hsCRP. While it is not possible to strictly isolate the effects of the DASH diet and WFPB diet in this study due to carryover effects from week to week, a pattern emerged. For most outcomes, initial benefits resulting from a DASH diet became significantly greater after switching to a WFPB diet for 7 days and then these benefits regressed toward baseline upon resumption of the DASH diet.

Participants in this study had more advanced diabetes than subjects had in many previous nutrition interventions. Other plant-based dietary interventions that have reported insulin adjustments include a study conducted in a metabolic ward and a study of individuals in a residential health program. Anderson et al. found that lean men in a metabolic ward who consumed a weight-maintaining high-carbohydrate, high fiber diet, reduced their insulin from 26 units/day to 11 units/day, on average, over the course of 16 days[23]. Men with higher insulin requirements were more refractory to the effects of dietary intervention. Separately, Barnard et al. published an analysis from the Pritikin program, a residential program utilizing a plant-based diet and exercise[24]. Patients more than 10% above their desirable body weight were placed on calorie restriction (900 kcal/day), while others were placed on an ad libitum plant-based diet. Of 60 individuals with type 2 diabetes, 17 were on insulin, with a range of doses from 14 to 75 units/day. After 3 weeks, 13 of the 17 individuals were off insulin entirely while fasting blood sugar improved. More recently, a randomized controlled trial using an ad libitum vegan diet found significant improvements in multiple outcomes, but excluded individuals who had been on insulin for more than 5 years[11]. Only 22% of the randomized controlled trial participants were on insulin and changes in insulin dosing were not reported. Given the more advanced nature of our participants' diabetes, both the rapidity and scale of changes observed are notable.

Both a DASH diet and a WFPB show benefit. The design of this study does not permit a strict comparison of the two diets because there was no wash out period and there were carryover effects from one diet week to the next. Despite these limitations, the trajectory of most outcomes is similar: There were improvements during the DASH 1 week, additional improvements during the WFPB week, and then a regression toward baseline during the DASH 2 diet. This suggests that the DASH diet was less efficacious than the WFPB diet among most outcomes studied. Interestingly, most outcomes after the DASH 2 week were similar to the outcomes at the end of DASH 1. This suggests that a) many of these outcomes change very quickly and b) participants adhered to the DASH diet similarly well in both DASH weeks, despite making large changes during the WFPB diet week in between.

The benefits seen in this study are likely related to many mechanisms working simultaneously. During all diet weeks, participants reported consuming fewer calories, which is consistent with the observed weight loss of 3% of total body weight by the end of the study. Compared to baseline, there was a 13%, 18%, and 18% reduction in calorie intake during the DASH 1, WFPB, and DASH 2 weeks, respectively, which was associated with a 24%, 39%, and 30% reduction in insulin requirements. However, calorie reduction and weight loss are not the sole contributing factors resulting in the observed changes. During the final DASH 2 week, participants continued consuming fewer calories, resulting in additional weight loss, and yet most outcomes regressed back towards baseline.

Comprehensive changes in nutrient intake are likely to be contributing as well. Fiber intake has consistently been found to benefit both glycemic control and cardiovascular risk factors[25, 26]. In addition, increased fat intake can lead to increased intramyocellular lipids and decreased insulin sensitivity[15, 16, 27]. Saturated fat appears to be particularly deleterious[28]. Early observations, published case series and several controlled interventions[11, 23, 24, 29–36] have found that diets higher in carbohydrate and lower in

fat can offer significant benefits for glycemic control and related comorbidities. The DASH diet results in moderate changes in the intake of these nutrients, and the WFPB results in even larger changes, which appears to mirror the difference in clinical efficacy observed in this study.

Changes in cardiometabolic risk factors were large. Statistically and clinically significant decreases in total and LDL cholesterol were perhaps even more notable given that 73% of the participants were already on cholesterol-lowering medication at baseline. Similarly, inflammation, as assessed by hsCRP, was 42% lower by the end of the WFPB week. A reduction in inflammation is another mechanism by which both cardiovascular risk and glycemic control improve[37]. Given that the majority of individuals with diabetes die from cardiovascular disease, this is a welcome effect of diets that simultaneously offer large and rapid benefits for glycemic control.

Changes in leptin, which is stimulated by insulin and affects appetite and other processes[38], were consistent with other observed changes in this study. Hyperleptinemia reflects a state of leptin resistance and is implicated in obesity. Our findings are consistent with previous studies which have found that energy restriction[39], low-fat[40], and low-protein[41] dietary intakes can lower leptin levels, reflecting reduced leptin resistance. Adiponectin levels did not significantly change during this study, which may reflect the fact that adiponectin does not change as rapidly in response to acute dietary changes compared to related outcomes[42].

There are numerous strengths and limitations of this study. The study duration only allows us to characterize short-term changes in outcomes. Further, because there were carryover effects from week to week and there were no washout periods, the effects of the two dietary interventions cannot be isolated. Generalizability is reduced in our study due to the smaller sample size, particularly the relatively advanced nature of our participants' diabetes. It is possible that individuals with more recently diagnosed diabetes, who require no or less insulin, respond differently than what is observed here. It would be reasonable to hypothesize that they may have an even more robust response.

Generalizability is also limited by the fact that we provided prepared meals. Most patients will not achieve the abrupt, large dietary changes implemented here, which were made more convenient by having prepared meals available. Nonetheless, some patients may have sufficient motivation to make large changes quickly, particularly when supported with dietary counseling. A wide array of resources is available to help motivated individuals quickly adopt a DASH diet or a WFPB diet. Our goal was to characterize the acute changes in insulin requirements from dietary patterns consumed as intended, not dietary patterns that were only partially implemented. As a result, a strength of our study was the large dietary changes achieved, which were done without mandated calorie or portion restriction and were not confounded by mandated changes in physical activity or other lifestyle changes. Our participants lived in the community and conducted their lives as normal during their participation, which may allow for greater generalizability than previous interventions that have required participants to be housed in a residential program or metabolic ward.

In conclusion, this study demonstrates that adopting a DASH diet or a WFPB diet can result in large and rapid changes in insulin requirements, insulin resistance, cholesterol, and inflammation among individuals with insulin-dependent type 2 diabetes, with greater dietary changes producing greater benefits. These findings are relevant for counseling motivated patients who may wish to adopt a plant-based diet and need guidance regarding medication deprescribing. This study also demonstrates that patients with more advanced type 2 diabetes may still realize large, comprehensive, and rapid benefits related to glycemic control, medication requirements, and cardiovascular risk factors from dietary change. These findings have important implications not only for individual health risks but also cost of care. Additional study is warranted to assess sustainability of behavioral changes and durability of outcomes over time.

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Data Availability

The data underlying this article will be made available by request at www.figshare.com. Email Thomas_campbell@urmc.rochester.edu for access.

Abbreviations:

CGM	Continuous glucose monitor
DASH	Dietary Approaches to Stop Hypertension
WFPB	Whole-food, plant-based

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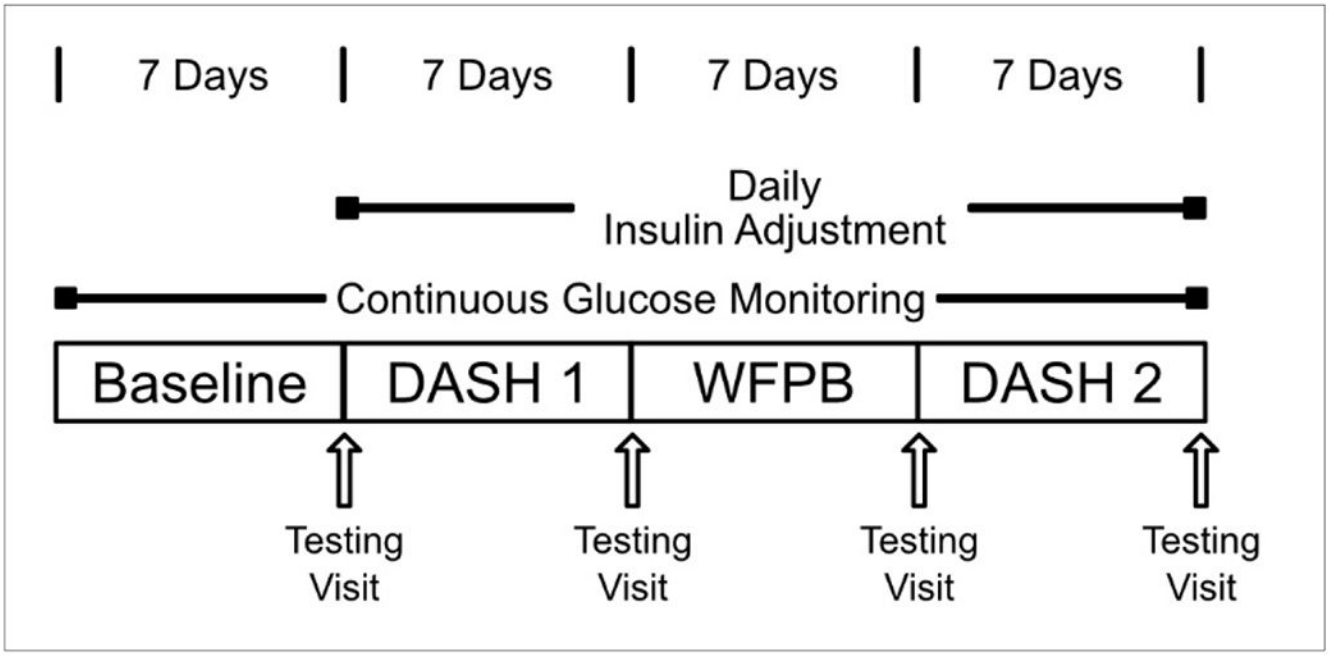

Figure 1.
Study Schema

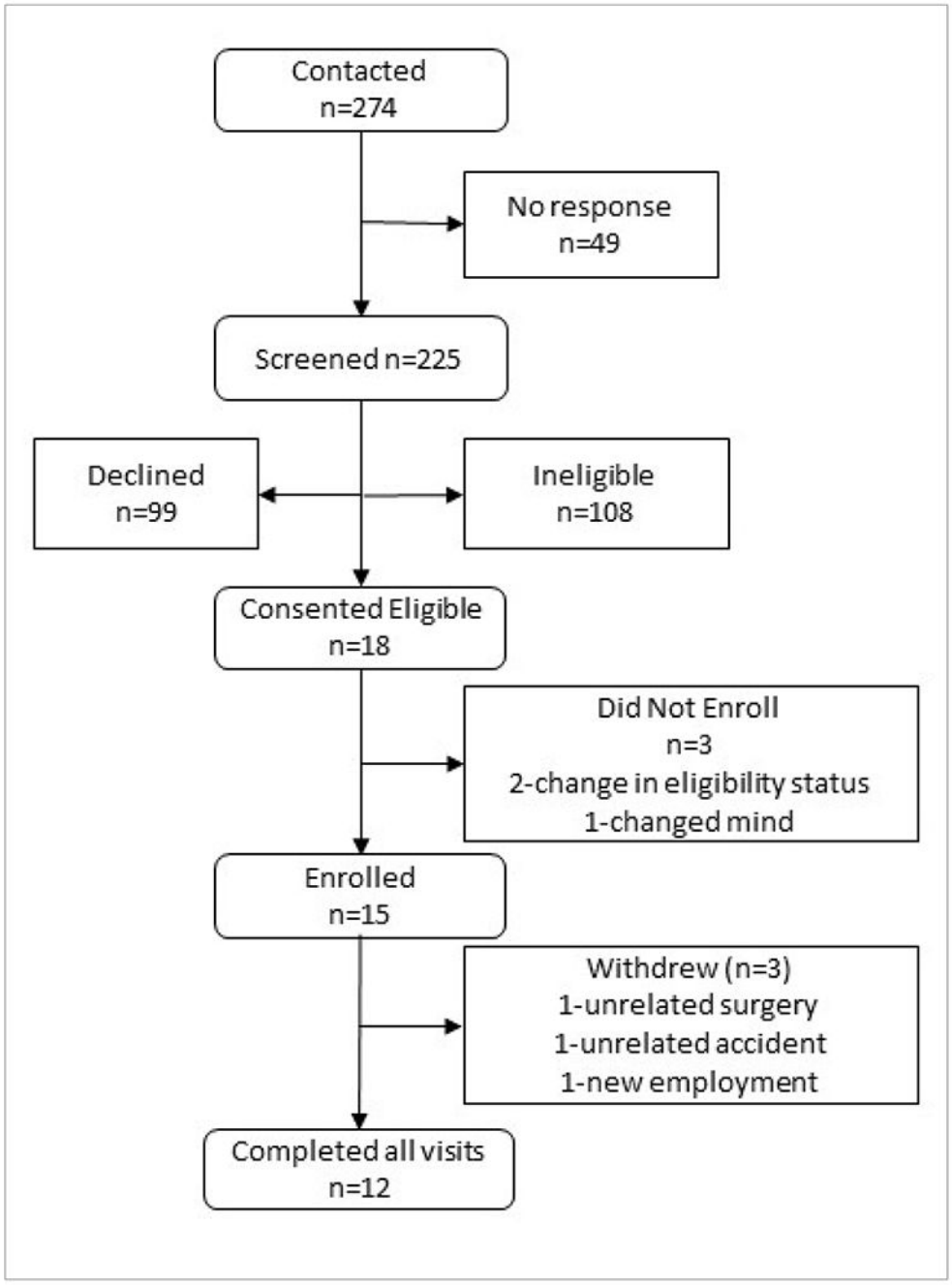

Figure 2.
Consort Diagram

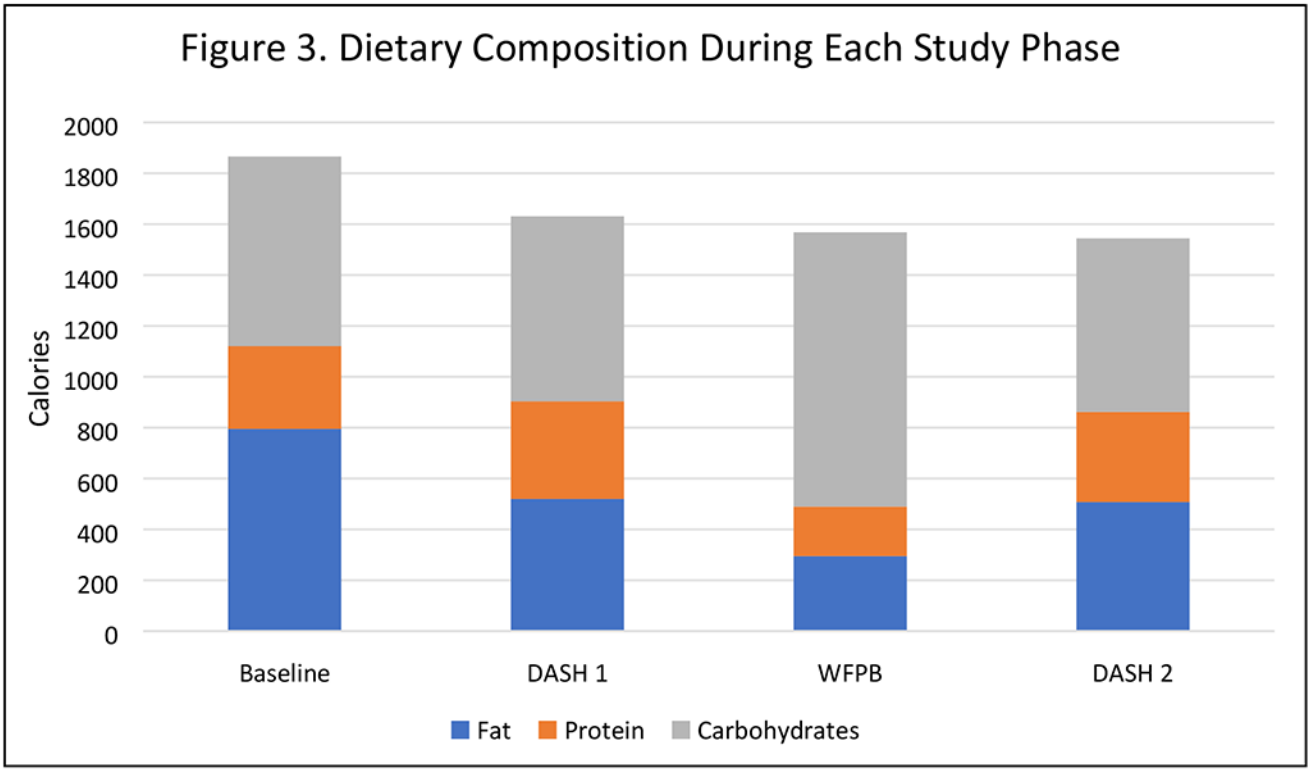

Figure 3.
Dietary Composition During Each Study Phase

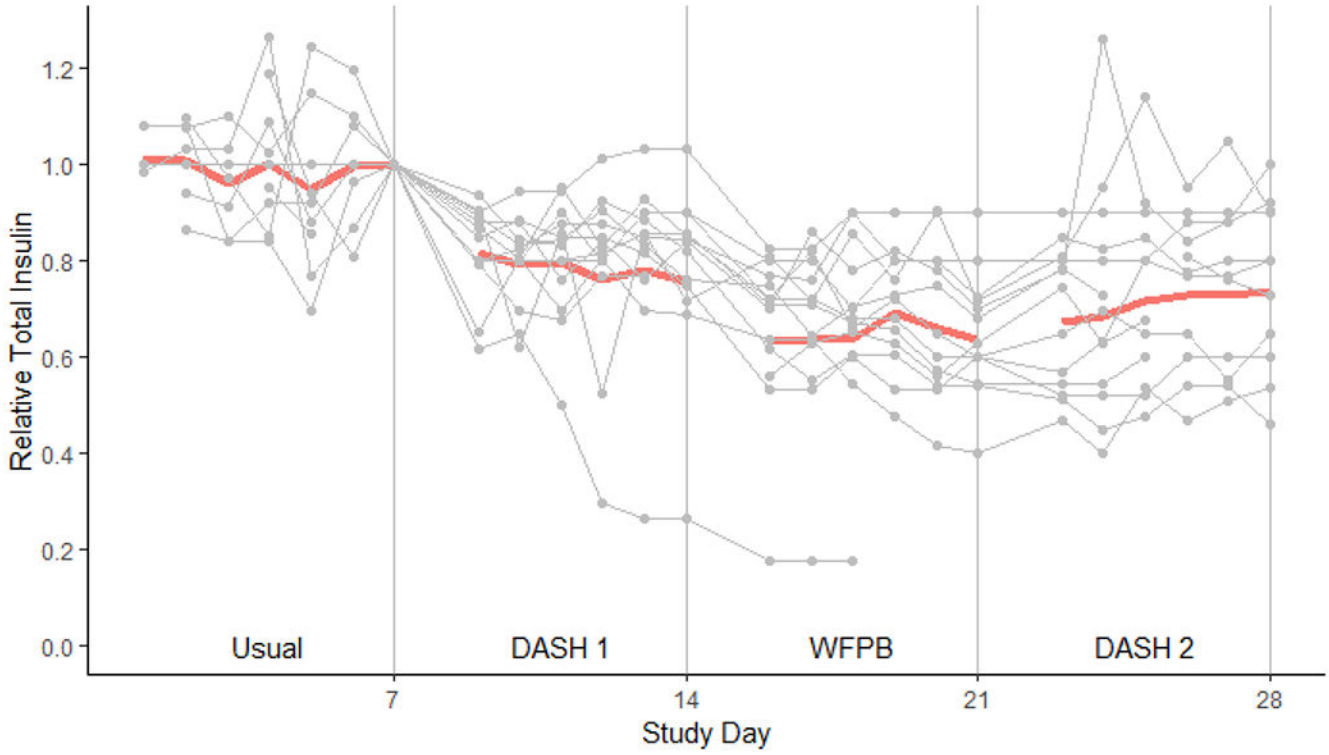

Figure 4. Relative Daily Insulin Usage During Four Study Phases

Bold line denotes the geometric mean total daily insulin usage relative to the insulin dose at the end of the baseline week. Light gray lines with circles are trajectories of each individual participant. 1st day of each diet is omitted due to non-dietary influence of the OGTT.

Table 1.

Baseline Characteristics (n=15)

Age	Mean, years (SD)	56.7 (±14.3)
Gender	Female, n (%)	9 (60.0)
	Male, n (%)	6 (40.0)
Race	White, n (%)	10 (66.7)
	African American, n (%)	3 (20.0)
	American Indian, n (%)	1 (6.7)
	No Response, n (%)	1 (6.7)
Ethnicity	Hispanic/Latino, n (%)	2 (13.3)
	Not Hispanic/Latino, n (%)	13 (86.7)
Weight	Mean, kg (SD)	97.5 (±19.1)
BMI	Mean, kg/m^2 (SD)	34.3 (±5.3)
BMI category	Overweight (BMI 25-29.9), n (%)	5 (33.3)
	Class 1 obesity (BMI 30-34.9), n (%)	4 (26.7)
	Class 2 obesity (BMI 35-39.9), n (%)	3 (20.0)
	Class 3 obesity (BMI >40), n (%)	3 (20.0)
Age at diabetes diagnosis	Mean, years (SD)	44.8 (±14.7)
Years elapsed since diagnosis	Mean, years (SD)	12.0 (±6.6)
Most recent HgbA1C	Mean, % (SD)	8.4 (±0.7)
	Mean, mmol/mol (SD)	68 (±2.2)
Medicines Used	Basal Insulin, n (%)	15 (100.0)
	Prandial Insulin, n (%)	12 (80.0)
	Metformin, n (%)	6 (40.0)
	GLP-1, n (%)	9 (60.0)
	SGLT2-inhibitor, n (%)	0 (0.0)
	Antihypertensive, n (%)	9 (60)
	Cholesterol-lowering, n (%)	11 (73.3)
	Heartburn Control, n (%)	10 (66.7)
	Depression/Anxiety Control, n (%)	7 (46.7)
Total Daily Insulin Dose	Mean, units/day (SD)	90.9 (59.9)
	Geometric mean, units/day (SD Factor)	74 (2.0)

Table 2.

Mean Dietary Intake at Baseline and Changes During Each Study Phase

	Unit	Baseline Diet	DASH 1	WFPB	DASH 2
Total energy	Kcal (95% CI)	1846 (1660, 2031)	**−264 (−436, −93)**	**−358 (−530, −187)**	**−350 (−526, −174)**
Carbohydrates	grams (95% CI)	186 (161, 212)	−5 (−33, 24)	**83 (55, 112)**	−16 (−45, 13)
	% of total kcal (95% CI)	39.7 (36.8, 42.6)	**4.9 (0.9, 8.9)**	**29.9 (25.8, 33.9)**	4.0, (0, 8.1)
Total Protein	grams (95% CI)	81 (71, 92)	**15 (4, 25)**	**−33 (−43, −22)**	7 (−4, 18)
	% of total kcal (95% CI)	18.0 (16.5, 19.6)	**5.8 (3.7, 8.0)**	**−6.8 (−9.0, −4.7)**	**5.6 (3.4, 7.8)**
Vegetable Protein	grams (95% CI)	26 (21, 31)	5 (0, 10)	**22 (17, 28)**	4 (−1, 10)
Total Fat	grams (95% CI)	88 (80, 97)	**−31 (−40, −21)**	**−56 (−65, −46)**	**−32 (−41, −23)**
	% of total kcal (95% CI)	41.6 (39.3, 44.0)	**−10.1 (−13, −7.0)**	**−22.5 (−25.6, −19.4)**	**−8.9, (−12.1, −5.8)**
Saturated Fat	grams (95% CI)	29 (26, 32)	**−13 (−17, −10)**	**−23 (−27, −20)**	**−14 (−18, −11)**
	% of total kcal (95% CI)	13.6 (12.5, 14.6)	**−5.0 (−6.3, −3.7)**	**−10.3 (−11.7, −9.0)**	**−4.8 (−6.2, −3.5)**
Fiber	g/1000kcal (95% CI)	11 (9, 13)	**9 (7, 10)**	**21 (19, 23)**	**9, (7, 11)**
Sodium	mg (95% CI)	3699 (3181, 4218)	**−1644 (−2297, −992)**	**−1413 (−2066, −761)**	**−1784 (−2451, −1117)**
Dietary Cholesterol	mg (95% CI)	380 (325, 435)	**−84 (−148, −21)**	**−379, (−442, −315)**	**−96 (−161, −31)**

Bolded values have p value of <0.05 when compared to baseline

Table 3.

Geometric Mean Insulin and Glucose Outcomes at Baseline and Relative Changes During Diet Phases

	Baseline	DASH1 v Baseline	WFPB v Baseline	DASH2 v Baseline	WFPB v DASH1	WFPB v DASH2	DASH2 v DASH1
Daily Insulin Dose, units	74.0 (49.8, 110)	**0.76 (0.66, 0.87)**	**0.61 (0.53, 0.71)**	**0.7 (0.61, 0.82)**	**0.81 (0.7, 0.94)**	0.87 (0.75, 1.01)	0.93 (0.8, 1.08)
Average 24hr Blood Glucose, mg/dL	155 (138, 173)	**0.76 (0.66, 0.87)**	**0.78 (0.67, 0.9)**	**0.76 (0.65, 0.87)**	1.03 (0.89, 1.18)	1.03 (0.88, 1.19)	1 (0.87, 1.15)
Fasting Blood Glucose, mg/dL	165 (151, 180)	**0.85 (0.77, 0.94)**	**0.71 (0.64, 0.78)**	**0.81 (0.73, 0.9)**	**0.83 (0.75, 0.92)**	**0.87 (0.79, 0.97)**	0.95 (0.85, 1.05)
Insulin Sensitivity Index	1.62 (0.95, 2.76)	1.17 (0.95, 1.44)	**1.38 (1.11, 1.71)**	1.04 (0.84, 1.29)	1.18 (0.96, 1.45)	**1.33 (1.07, 1.65)**	0.89 (0.73, 1.09)
HOMA-IR	7.52 (4.34, 13.01)	**0.7 (0.54, 0.91)**	**0.51 (0.39, 0.68)**	**0.72 (0.54, 0.95)**	**0.74 (0.56, 0.96)**	**0.72 (0.54, 0.96)**	1.02 (0.77, 1.37)
Urinary Glucose, mg/dL	16.5 (6.5, 41.7)	**0.11 (0.04, 0.31)**	**0.08 (0.03, 0.24)**	**0.19 (0.06, 0.57)**	0.76 (0.26, 2.19)	0.43 (0.14, 1.31)	1.75 (0.58, 5.2)

$p<0.05$ shown in bold. Numbers in parentheses are 95% confidence intervals.

Table 4.

Geometric Mean Cardiometabolic Outcomes at Baseline and Relative Changes During Diet Phases

	Baseline	DASH1 v Baseline	WFPB v Baseline	DASH2 v Baseline	WFPB v DASH1	WFPB v DASH2	DASH2 v DASH1
Total Cholesterol, mg/dL	156 (138, 176)	0.96 (0.9, 1.02)	**0.82 (0.77, 0.88)**	**0.9 (0.84, 0.96)**	**0.86 (0.81, 0.92)**	**0.91 (0.86, 0.97)**	0.94 (0.88, 1)
Triglycerides, mg/dL	124 (98, 158)	1.04 (0.94, 1.15)	0.98 (0.88, 1.09)	0.97 (0.87, 1.08)	0.94 (0.85, 1.04)	1.01 (0.91, 1.12)	0.93 (0.84, 1.04)
HDL Cholesterol, mg/dL	43 (37, 50)	0.98 (0.92, 1.03)	**0.92 (0.87, 0.98)**	**0.94 (0.88, 1)**	0.95 (0.89, 1)	0.98 (0.93, 1.04)	0.96 (0.91, 1.02)
LDL Cholesterol, mg/dL	82 (64, 105)	0.89 (0.79, 1.01)	**0.69 (0.61, 0.78)**	**0.86 (0.75, 0.97)**	**0.78 (0.69, 0.88)**	**0.81 (0.71, 0.92)**	0.96 (0.85, 1.09)
Weight, kg	95.3 (85.5, 106.2)	**0.98 (0.98, 0.99)**	**0.97 (0.97, 0.98)**	**0.97 (0.96, 0.98)**	**0.99 (0.98, 1)**	1 (1, 1.01)	**0.99 (0.98, 0.99)**
Systolic BP, mmHg	130 (124, 137)	0.99 (0.96, 1.02)	0.98 (0.95, 1.01)	**0.96 (0.92, 0.99)**	0.99 (0.96, 1.03)	1.03 (0.99, 1.06)	0.97 (0.94, 1)
Diastolic BP, mmHg	69 (64, 74)	1.03 (0.97, 1.1)	0.96 (0.9, 1.03)	0.97 (0.91, 1.04)	0.94 (0.88, 1)	0.99 (0.93, 1.06)	0.95 (0.89, 1.01)
hsCRP, mg/L	2.3 (1.3,4.1)	0.84 (0.56, 1.26)	**0.58 (0.38, 0.88)**	0.85 (0.55, 1.3)	0.69 (0.45, 1.05)	0.68 (0.44, 1.05)	1.01 (0.66, 1.55)
Adiponectin, ng/mL	3014 (2345, 3870)	0.99 (0.8, 1.23)	0.92 (0.74, 1.14)	1.08 (0.86, 1.35)	0.93 (0.75, 1.15)	0.85 (0.68, 1.06)	1.09 (0.87, 1.36)
Leptin, ng/mL	33 (18, 62)	0.77 (0.58, 1.01)	**0.72 (0.55, 0.96)**	0.87 (0.66, 1.17)	0.94 (0.72, 1.24)	0.83 (0.62, 1.1)	1.14 (0.86, 1.51)

p<0.05 shown in bold. Numbers in parentheses are 95% confidence intervals.