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Avocado Consumption, Abdominal Adiposity, and Oral Glucose Tolerance Among Persons with Overweight and Obesity

Naiman A Khan,[1,2] Caitlyn G Edwards,[2] Sharon V Thompson,[2] Bridget A Hannon,[2] Sarah K Burke,[3] Anne DM Walk,[4] Richard WA Mackenzie,[5] Ginger E Reeser,[1] Barbara H Fiese,[6,7] Nicholas A Burd,[1,2] and Hannah D Holscher[1,2,8]

[1]Department of Kinesiology and Community Health, University of Illinois, Urbana, IL, USA; [2]Division of Nutritional Sciences, University of Illinois, Urbana, IL, USA; [3]Department of Physical Therapy, University of Florida, Gaineville, FL, USA; [4]Department of Psychology, Eastern Illinois University, Charleston, IL, USA; [5]Department of Life Science, Whitelands College, University of Roehampton, London, UK; [6]Department of Human Development and Family Studies, University of Illinois, Urbana, IL, USA; [7]Family Resiliency Center, University of Illinois, Urbana, IL, USA; and [8]Department of Food Science and Human Nutrition, University of Illinois, Urbana, IL, USA

ABSTRACT

Background: Although intake of Hass avocado has been cross-sectionally linked to lower abdominal obesity, knowledge of the effects of avocado consumption on abdominal adiposity and glycemic outcomes remains limited.

Objective: The effects of avocado consumption on abdominal adiposity, insulin resistance, oral-glucose-tolerance test (OGTT), and estimated β-cell function were evaluated.

Methods: A total of 105 adults aged 25–45 y (61% female) with BMI ≥25 kg/m^2 were randomly assigned to an intervention (N = 53) that received a daily meal with 1 fresh Hass avocado or a control (N = 52) that received an isocaloric meal with similar ingredients without avocado for 12 wk. DXA was used to assess the primary outcomes of abdominal adiposity [visceral adipose tissue (VAT), subcutaneous abdominal adipose tissue (SAAT), and the ratio of VAT to SAAT (VS Ratio)]. Fasted glucose and insulin were used to assess the primary outcomes of insulin resistance (HOMA-IR), and insulin sensitivity (Matsuda index) and β-cell function (Insulinogenic index) were estimated using an OGTT. Changes between groups were compared using an ANCOVA. Secondary analyses were conducted based on sex.

Results: The control group exhibited a greater reduction in SAAT [–54.5 ± 155.8 g (control) compared with 17.4 ± 155.1 g (treatment), $P = 0.017$] and increase in VS Ratio [0.007 ± 0.047 (control) compared with –0.011 ± 0.044 (treatment), $P = 0.024$]. Among females, the treatment group exhibited a greater reduction in VAT [1.6 ± 89.8 g (control) compared with –32.9 ± 81.6 g (treatment), $P = 0.021$] and VS Ratio [0.01 ± 0.05 (control) compared with –0.01 ± 0.03 (treatment), $P = 0.001$]. Among males, there was no significant difference between groups in changes in abdominal adiposity or glycemic outcomes.

Conclusions: Daily consumption of 1 fresh Hass avocado changed abdominal adiposity distribution among females but did not facilitate improvements in peripheral insulin sensitivity or β-cell function among adults with overweight and obesity. This study was registered at clinicaltrials.gov as NCT02740439. *J Nutr* 2021;151:2513–2521.

Keywords: fiber, monounsaturated fatty acids, abdominal adiposity, insulin, obesity

Introduction

The epidemic of elevated overweight and obesity presents a major public health challenge in the USA, currently affecting ~70% of the adult population (1). Further, increased abdominal obesity, a hallmark of fat or adiposity-related metabolic dysfunction, impacts over 1 in 3 adults (2). Visceral adipose tissue (VAT) is more closely associated with obesity-related metabolic diseases than subcutaneous abdominal adipose tissue (SAAT) (3–5). Increased VAT has been cross-sectionally and prospectively implicated in impaired glucose tolerance and insulin resistance, and onset of type 2 diabetes, relative to other adipose depots (6, 7). Dietary intervention offers a potentially efficacious solution for abdominal obesity management; however, the influence of diet in reducing VAT is unclear. Weight loss interventions can be effective in reducing VAT and risk of type 2 diabetes (8, 9), but unfortunately inducing and maintaining weight loss is unsuccessful for most individuals (10). Therefore, dietary approaches that promote reduction in VAT and reduction in type 2 diabetes risk, without relying on hypocaloric diets and weight loss, may hold translational potential for individuals with overweight and obesity.

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Regular consumption of nutrient-dense whole foods can serve as a nonpharmacological approach to modifying adipose tissue distribution and alleviating the metabolic effects of adiposity. The avocado (*Persea americana*) is a fruit that is rich in dietary fiber and MUFAs, 2 nutrients that are beneficial for metabolic health (11). One fresh Hass avocado (~136 g) contains ~13 g MUFAs, 10 g fiber, and carotenoids and other bioactive components (12). Diets rich in MUFAs and fiber have received considerable attention for their potential to reduce obesity and lower the risk of type 2 diabetes (13–15). Avocado consumers have lower abdominal obesity compared with nonconsumers (11, 16). Further, in a longitudinal study among over 55,000 individuals, habitual consumption of avocados was associated with lower weight gain and reduced risk of having overweight or obesity when assessed 11 y later (17). In a recent 12-wk randomized controlled weight loss study, it was demonstrated that avocados can be consumed as part of a hypocaloric diet weight loss program as well (18). Therefore, avocado consumption is not only a marker of a higher quality diet but can also improve metabolic health and weight status. However, the effects of daily avocado consumption on adipose tissue distribution and related insulin resistance, insulin sensitivity, and pancreatic β-cell function are unclear. The present work involved an investigator-blinded randomized controlled trial to examine the effects of consuming a daily meal with an avocado, relative to an isocaloric meal without the avocado, on abdominal adiposity, insulin resistance, and oral glucose tolerance among young-to-middle-aged adults with overweight or obesity. We hypothesized that participants consuming a daily meal with an avocado would exhibit greater declines in VAT, VS Ratio, insulin resistance, and improvement in glycemic outcomes.

Methods

Participants and study design

A randomized controlled trial design [*Persea americana* for Total Health (PATH) Study] was undertaken to assess the effects of daily avocado consumption on abdominal adiposity and glycemic measures among adults with overweight or obesity. Data collection procedures were administered at baseline, prior to treatment allocation, and at follow-up 12 wk later. All subjects provided written informed consent prior to study participation. Procedures were administered in accordance with the Declaration of Helsinki and were approved by the Ethics Committee of the University of Illinois. The study was registered as a clinical trial on clinicaltrials.gov (NCT02740439). Adults aged between 25 and 45 y with a BMI ≥25 (in kg/m^2) were recruited using university e-mail listservs and flyers posted in community buildings and on buses frequented by the public. Data were collected in central Illinois between 2016 and 2018. Participant exclusion criteria included BMI <25, pregnancy or lactation, tobacco use, food allergies and lactose intolerance, latex allergy, prior diagnosis of cognitive, metabolic, and gastrointestinal disease, use of medications that alter normal bowel function and metabolism, and prior malabsorptive or restrictive bariatric surgery within previous 2 y. Given that previously published research on avocado consumption effects on adipose tissue distribution and glucose tolerance were lacking, an *a priori* power calculation using a moderate effect size (*Cohen's d* = 0.50), 2-sided α of 0.05, and 80% power, estimated that a sample size of 64 participants/group would be sufficient to address the primary study aims.

Study treatment and control meals

Randomization was completed by a member of the research team (ADMW) who was not involved in data collection or administration of the intervention. Participants randomly assigned to the treatment group consumed 1 meal a day with 175 g (male) and 140 g (female) fresh Hass avocado, whereas the control group consumed an isocaloric meal matched for macronutrient composition without an avocado. A complete description of the meals and ingredient list can be found in **Supplemental Table 1**. Per serving (50 g), an avocado provides 80 kcal. The majority of the calories in avocados (~90%) are derived from fats with the greatest proportion accounted for by MUFAs (5 g/serving) and 1 g/serving for polyunsaturated and 1 g/serving for saturated fats. The carbohydrates are predominantly in the form of dietary fiber (4 out of 5 g/serving) whereas proteins are only 1 g/serving. Avocados also provide ≤20 minerals and vitamins. As outlined in **Table 1**, owing to the macronutrient composition of avocados, the treatment meals were higher in total fiber and lower in saturated fats and higher in MUFAs. Over 90% of the ingredients were identical between the meals but were scaled to meet the desired caloric and macronutrient profiles. The energy content and proportion of macronutrients of meals for females was 20% lower compared with males due to estimated energy needs. The study meals were provided on a 7-d menu cycle designed to be similar to a typical American diet and meet the Acceptable Macronutrient Distribution Ranges (AMDR) set by the Institute of Medicine (~45% carbohydrates, 35% fat, and 15% protein). Examples of meals included modified versions of Penne Pasta, Cranberry Salad, Spanish Rice, Asian Penne, Turkey Wrap, Spring Bowl, and an Egg Scramble. Participants traveled to the test site twice weekly to pick up meals. Insulated meal coolers, ice packs, and information about food safety procedures were provided. Compliance was assessed using daily logs that participants completed to indicate meal consumption and, for participants in the intervention, avocado consumption. Concealment of allocation was maintained using sequentially numbered containers for meal dispensation. Additionally, staff who prepared and provided participants with the meals were not involved in the data collection procedures.

Dietary assessment

Background diet was monitored prior to and during the final week of the intervention. Participants were asked to record all beverages and foods consumed for ≥7 d and were provided a food diary with detailed instructions given by a trained member of the research staff at the completion of their first laboratory visit. In addition, the record contained written instructions for recording food intake (including how to describe food preparation methods, added fats, brand names, and ingredients of mixed dishes and recipes) and visual aids to estimate serving sizes. Trained staff entered food records into the Nutrition Data Systems-Research Version 2015 [Nutrition Coordinating Center (NCC), University of Minnesota, Minneapolis, MN, USA] software under supervision of a registered dietitian (NAK).

Physical activity

Participants were asked to recall their average weekly physical activity during their leisure time over the past month using the Godin Leisure Time Exercise Questionnaire (GLTEQ) (19, 20). The GLTEQ contains 3 open-ended physical activity questions pertaining to the average frequency of mild, moderate, and strenuous physical activities

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Address correspondence to NAK (e-mail: nakhan2@illinois.edu).
Abbreviations used: FDR, false discovery rate; GLTEQ, Godin Leisure Time Exercise Questionnaire; IGI, insulinogenic index; OGTT, oral-glucose-tolerance test; PATH, *Persea americana* for Total Health; SAAT, subcutaneous abdominal adipose tissue; VAT, visceral adipose tissue.

TABLE 1 Nutrient comparison between meals with avocado (treatment) and without (control) avocado provided to participants with overweight or obesity[1]

	Control		Treatment	
Nutrient	Males	Females	Males	Females
Energy, kcal	662	530	660	528
Total fiber, g	4.0	3.2	16.0	12.8
Soluble fiber, g	1.0	0.8	6.0	4.8
Pectins, g	0.0	0.0	4.0	3.2
Insoluble fiber, g	3.0	2.4	10.0	8.0
Protein, %	16	12.8	14	11.2
Total fat, %	39		40	
SFAs, %	17		7	
MUFAs, %	10		24	
PUFAs, %	9		5	
Carbohydrate, %	45		45	

[1] Comparison of nutritional profiles between daily meals consumed by participants with (intervention) and without a fresh Hass avocado (treatment).

(with examples of each) during free time during a typical week. All participants were asked to refrain from changes in their physical activity levels throughout the intervention.

Anthropometrics and abdominal adiposity assessment

Standing height and weight measurements were completed to calculate BMI with participants wearing lightweight clothing and no shoes. Height and weight were assessed using a stadiometer (model 240; SECA) and a digital scale (WB-300 Plus; Tanita), respectively. Measures were recorded in triplicate and the average value was used in the analyses. Whole body, VAT, and SAAT components were estimated using a Hologic Horizon W densitometer using the standard software (APEX Software version 5.6.0.5; Hologic). These procedures have been previously described in detail (21, 22).

Oral-glucose-tolerance test.

At baseline and 12 wk, a standard oral-glucose-tolerance test (OGTT) was administered following a 12-h overnight fast. Participants rested for ≥30 min prior to the insertion of a Teflon catheter into an antecubital vein for repeated blood sampling and remained patent by a 0.9% saline drip. After baseline blood collection, participants ingested 75 g glucose bolus (NOW foods) dissolved in 250 mL of water within 2 min (t = 0 min) (21). Venous blood was collected at the following time points: 0, 15, 30, 45, 60, 90, and 120 min after glucose ingestion into EDTA containing tubes (BD Biosciences). Blood glucose concentration was determined using a biochemical analyzer (YSI 2900 Life Sciences) in duplicate and subsequently centrifuged at 1000 × g for 10 min at 4°C. Aliquots of plasma were frozen and stored at –20°C until analyses. Plasma insulin concentrations were determined using a commercially available ELISA (ALPCO).

Plasma glucose and insulin concentrations were used to determine the Matsuda index and HOMA-IR according to established formulas (23, 24). The Matsuda index was calculated by:

$$\frac{10,000}{\sqrt{((fasting\,glucose \times fasting\,insulin) \times (average\,glucose\,values) \times (average\,insulin\,values))}} \quad (1)$$

HOMA-IR was calculated by:

$$\frac{Fasting\,Glucose \times Fasting\,Insulin}{405} \quad (2)$$

Further, the insulinogenic index (IGI) was utilized as a measure of β-cell function and calculated as ratio of insulin concentration at 30 min minus fasting insulin to the difference of glucose at the same time (25).

Statistical analyses

Data from participants who completed the 12-wk intervention (control = 53, treatment = 52) were used to conduct per protocol analyses (see Figure 1). We applied a cutoff of 80% compliance for study meal consumption throughout the trial, for per protocol analyses. Additionally, intent-to-treat analyses were conducted among all participants who were randomly assigned and provided complete data at baseline. Missing values at follow-up were carried forward from baseline values for the intent-to-treat analyses.

Baseline differences in between groups were assessed by independent samples t-test. Primary analyses, i.e., intervention effects on abdominal adiposity (i.e., VAT, SAAT, VS Ratio), insulin resistance (i.e., HOMA-IR), and OGTT (i.e., Matsuda index and IGI) measures were subjected to a univariate ANCOVA whereby change (posttest–baseline) measures were compared between groups, following adjustment of changes in reported energy intake. Critical values were adjusted for false discovery rate (FDR) to act as a check on inflation of Type 1 error (26). In the present analyses, the FDR was set to 0.05, the acceptable level of family-wise error. Secondary analyses separated by sex were conducted since there were significant differences in adiposity variables between females and males. Statistical significance level was set at P <0.05 (2-tailed) and data were analyzed using SPSS version 25 (IBM).

Results

Per protocol analyses

Participants and baseline variables.

Participant recruitment and inclusion/exclusion is illustrated in Figure 1. One hundred and fifty-six participants who were randomly assigned provided complete data at baseline and 136 were retained in the study at follow-up. The overall retention rate of the study was 87%. There were no discernable differences in characteristics between participants who dropped out of the study compared with those who remained in the study. Specifically, there were no significant differences in age and baseline adiposity and glycemic variables between participants who dropped out compared with those who remained in the study (all Ps >0.209).

Following exclusion of participants who either did not provide follow-up data for adiposity variables or those who did not meet the compliance threshold of 80%, 105 participants were included in the final per protocol analyses for adiposity variables of interest. Only 64 participants [34 (control), 30 (treatment)] successfully completed both baseline and follow-up OGTT measures for calculating HOMA-IR, Matsuda index, and IGI.

Participant demographic and anthropometric information is summarized in Table 2. Persons with overweight comprised 41% of the sample whereas 59% had obesity. The majority

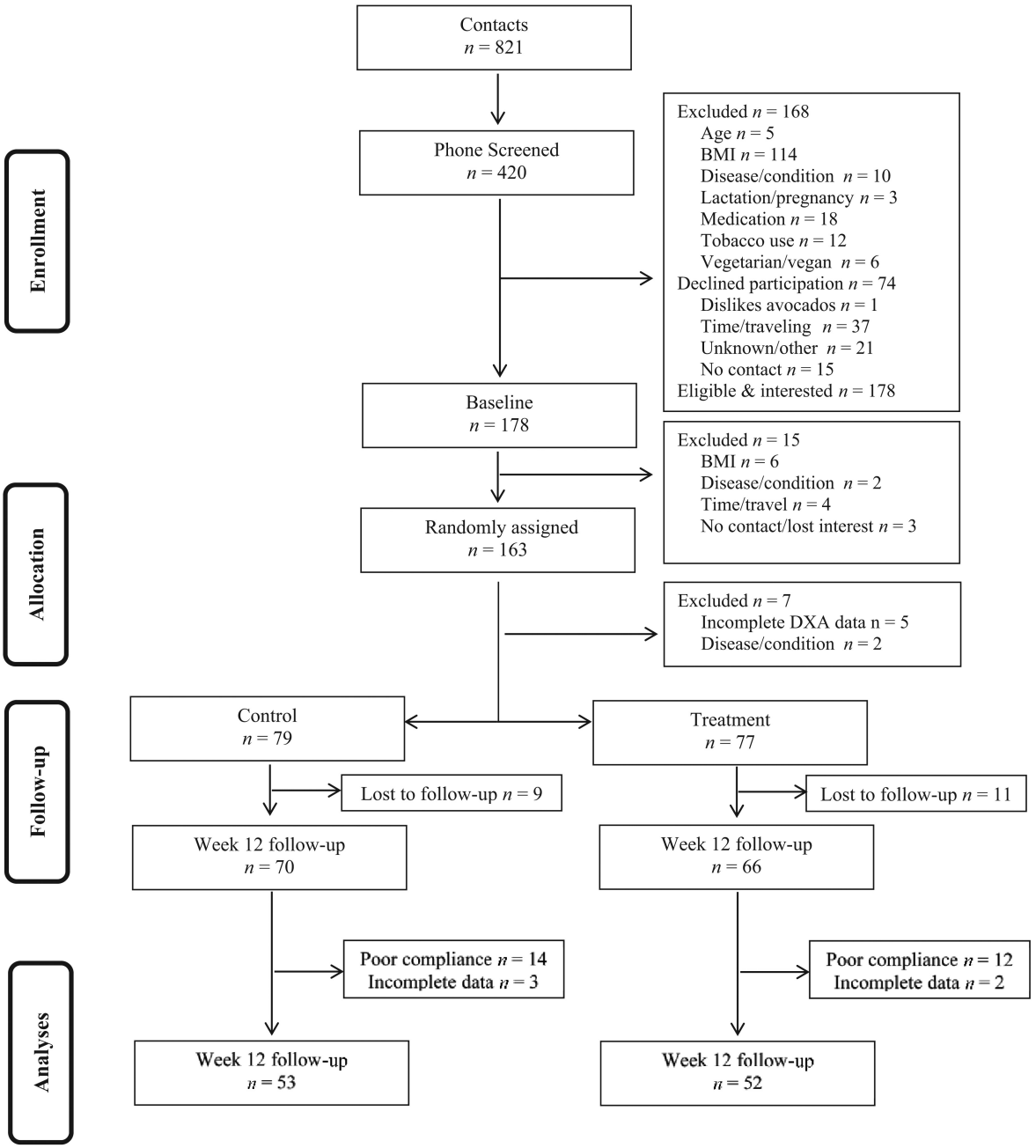

FIGURE 1 Participant recruitment and inclusion/exclusion information.

of the participants were of Caucasian descent (80%) and female (61%). Significant differences in adiposity variables were observed based on sex whereby females had higher SAAT (2383.9 ± 598.5 g compared with 1675.5 ± 749.8 g, P <0.001) whereas males had a higher VS Ratio (0.43 ± 0.14 compared with 0.30 ± 0.09, P <0.001). However, there were no differences in VAT between males and females [711.7 ± 303.7 g (females) compared with 678.0 ± 348.3 g (males), P = 0.601]. There were no significant differences between treatment and control group participants of the same sex.

Background diet and physical activity.

There were no statistically significant differences in changes in leisure time physical activity score between the treatment and control groups [–3.6 ± 29.9 (control) compared with 11.4 ± 41.6 (treatment), P = 0.59]. However, there was a significant difference between changes in energy consumption between the control and treatment groups [–109.7 ± 549.7 kcal (control) compared with 174.3 ± 568.4 kcal (treatment), P = 0.011]. As the intervention aimed to maintain overall caloric intake throughout the study and between groups, subsequent statistical analyses adjusted for change in energy consumption to account for background changes in energy consumption between groups.

Intervention effects on central adiposity.

The baseline values for the adiposity measures are summarized in Table 3 for descriptive purposes. Baseline and follow-up insulin resistance and sensitivity is described in Table 4. The summary of statistical tests contrasting change in adiposity

TABLE 2 Baseline demographic information and anthropometric characteristics of adults with overweight or obesity participating in the PATH randomized controlled trial[1]

	All (N = 105)	Control (N = 53)	Treatment (N = 52)
Age, y	34.5 ± 5.9	34.2 ± 6.0	34.9 ± 5.8
Race, *n* (%)			
White or Caucasian	83 (80)	42 (79)	41 (79)
Asian	11 (11)	5 (9)	6 (12)
Black or African American	5 (5)	3 (6)	2 (4)
American Indian or Alaska Native	1 (1)	1 (2)	0 (0)
Other and multiracial	4 (4)	2 (4)	2 (4)
Household income, *n* (%)			
≤$41,000	28 (27)	14 (26)	14 (26)
$41,000–$70,000	39 (37)	21 (40)	18 (35)
≥$70,000	38 (36)	18 (34)	20 (39)
Height, cm	171.2 ± 8.9	171.1 ± 9.6	171.2 ± 8.2
Weight, kg	95.7 ± 19.4	96.9 ± 20.5	94.5 ± 18.4
BMI, kg/m^2	32.6 ± 6.1	33.0 ± 6.2	32.1 ± 6.0
Overweight (25–29.9)	43 (41)	21 (40)	22 (42)
Obesity Class 1 (30–34.9)	32 (31)	14 (26)	18 (35)
Obesity Class 2 (35–39.9)	17 (16)	8 (15)	9 (17)
Obesity Class 3 (≥40)	13 (12)	10 (19)	3 (6)

[1] Continuous data presented as mean ± SD where indicated. PATH, *Persea americana* for Total Health.

and glycemic outcomes is summarized in Table 5. There was no significant difference between groups in VAT. The control group had a significantly larger reduction in SAAT. There was a significant difference between groups in change in VS Ratio. Examining the results based on sex revealed that, among females, there was a significant difference between groups in changes in VAT, SAAT, and VS Ratio. On the other hand, among males, there was no significant difference between groups in changes in VAT, SAAT, and VS Ratio. Following controlling for FDR, the differences in changes in VS Ratio between groups remained significant. Similarly, the differences in changes in VS Ratio and SAAT among females persisted following controlling for FDR.

Intervention effects on insulin resistance and sensitivity.
The baseline values for the glucose- and insulin-based outcomes are summarized in Table 4 and comparison of changes based on sex and group are summarized in Table 5. There was no difference between groups in changes in HOMA-IR ($P = 0.100$), Matsuda index ($P = 0.285$), and the IGI ($P = 0.67$). Similarly, there were no changes among females or males.

Intent-to-treat analyses

Intervention effects on central adiposity.
Intent-to-treat analyses for the adiposity variables were conducted among all participants who were randomly assigned and completed baseline testing in the control [N = 79 (52 females; 27 males)] and treatment [N = 77 (49 females; 28 males)] groups. There was no significant difference between groups in VAT ($P = 0.44$). The control group had a significantly larger reduction in SAAT ($P = 0.012$). However, there was a difference between groups in VS Ratio ($P = 0.045$). Examining the results based on sex revealed that, among females, there was no significant difference between groups in changes in VAT ($P = 0.227$). However, there were significant differences in SAAT ($P = 0.002$), and VS Ratio ($P = 0.010$). On the other hand, among males, there was no significant difference between groups in changes in VAT ($P = 0.940$), SAAT ($P = 0.545$), and VS Ratio ($P = 0.611$). Following controlling for FDR, the significant differences in changes in VS Ratio and SAAT among females persisted.

Intervention effects on insulin resistance and sensitivity.
There was a significant difference between groups in changes in HOMA-IR ($P = 0.036$). However, there was no significant

TABLE 3 Baseline and follow-up adiposity of adults with overweight or obesity participating in the PATH randomized controlled trial based on sex and group[1]

	Females				Males			
	Control (N = 34)		Treatment (N = 30)		Control (N = 19)		Treatment (N = 22)	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
Weight, kg	94.6 ± 18.6	94.4 ± 18.3	92.4 ± 16.6	92.0 ± 16.5	101.0 ± 23.5	99.9 ± 23.7	97.3 ± 20.7	97.9 ± 20.9
Fat, %	44.3 ± 6.2	44.0 ± 6.2	42.9 ± 4.3	42.5 ± 4.6	32.3 ± 8.6	31.6 ± 8.2	31.6 ± 7.6	31.9 ± 7.7
VAT, g	743.9 ± 334.0	745.5 ± 324.2	675.2 ± 266.1	642.3 ± 258.0	672.4 ± 409.3	618.4 ± 351.4	682.8 ± 295.8	664.7 ± 272.5
SAAT, g	2476.6 ± 595.0	2415.3 ± 633.8	2279.0 ± 594.7	2292.6 ± 599.4	1701.2 ± 792.4	1684.0 ± 867.2	1653.4 ± 729.2	1675.8 ± 744.2
VS Ratio	0.30 ± 0.10	0.31 ± 0.11	0.29 ± 0.08	0.28 ± 0.08	0.42 ± 0.16	0.40 ± 0.17	0.44 ± 0.12	0.41 ± 0.11

[1] Data presented as mean ± SD. PATH, *Persea americana* for Total Health; SAAT, subcutaneous abdominal adipose tissue; VAT, visceral adipose tissue; VS Ratio, visceral to subcutaneous abdominal adipose tissue.

TABLE 4 Baseline and follow-up insulin resistance and sensitivity of adults with overweight or obesity participating in the PATH randomized controlled trial based on sex and group[1]

	Females				Males			
	Control (N = 21)		Treatment (N = 16)		Control (N = 13)		Treatment (N = 14)	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
Glucose, mg/dL	83.5 ± 12.5	82.7 ± 11.5	77.5 ± 13.8	82.3 ± 11.0	80.4 ± 10.2	84.3 ± 14.0	80.7 ± 11.3	87.7 ± 8.7
Insulin, μIU/L	10.9 ± 6.8	11.0 ± 4.8	8.3 ± 3.7	9.5 ± 5.3	9.3 ± 4.7	9.7 ± 4.6	9.6 ± 5.9	11.3 ± 7.3
HOMA-IR	2.3 ± 1.7	2.3 ± 1.2	1.6 ± 0.9	2.0 ± 1.2	2.0 ± 1.3	2.0 ± 1.1	1.9 ± 1.2	2.5 ± 1.9
Matsuda index	5.4 ± 3.2	5.0 ± 2.7	6.7 ± 4.4	5.6 ± 3.8	5.2 ± 2.5	4.6 ± 2.4	5.5 ± 3.2	4.5 ± 2.5
Insulinogenic index	2.3 ± 2.8	2.0 ± 2.6	2.0 ± 2.2	1.8 ± 1.7	2.1 ± 4.1	1.2 ± 0.6	1.3 ± 1.2	1.5 ± 1.5

[1]Description of baseline insulin resistance and sensitivity values among participants with overweight and obesity allocated to a group consuming a daily fresh Hass avocado (treatment) compared with a group consuming an isocaloric meal without avocado (control) for 12 wk. Data presented as mean ± SD. PATH, *Persea americana* for Total Health.

difference between groups in changes in Matsuda index ($P = 0.286$) and the IGI ($P = 0.779$). There were no changes among females (all *P*s ≥0.161) or males (all *P*s ≥0.16). Following controlling for FDR, there were no significant differences in changes across glycemic outcomes.

Discussion

The present work determined the effects of daily avocado consumption on abdominal adiposity, insulin resistance, and oral glucose tolerance among adults with overweight and obesity. There were significant differences in VS Ratio between groups, likely due to the greater change in SAAT among control group participants. The greater reduction in SAAT among control group participants was an unexpected result. However, change in SAAT in the control group was not associated with changes in overall energy consumption or change in self-reported leisure time physical activity (data not shown). Therefore, although we do not know the cause of the SAAT change observed in the control group, this change is not related to self-reported changes in overall energy consumption and leisure time physical activity. Analyses based on sex revealed that females in the treatment group exhibited a greater reduction in VS Ratio whereas control group females had a greater reduction in SAAT. However, there were no improvements in HOMA-IR, insulin sensitivity, and β-cell function (i.e., IGI).

Although avocado consumption is a marker of higher diet quality and potentially protects against metabolic risk (11, 16, 27, 28), there has been limited experimental work on adiposity and oral glucose tolerance outcomes. A recent hypocaloric weight loss trial with the inclusion of avocado reported reductions in adiposity and improvements in presumably fasting glucose; however, there were no differences between the treatment and control groups (18). Previous research observed that avocado consumers had higher BMI, waist circumference, and metabolic syndrome risk (16). In a longitudinal study among over 55,000 older adults, it was observed that, among avocado consumers who had healthy weight status at baseline, there was a reduction in the odds of developing overweight or obesity compared with those who did not eat avocado (17). The present work revealed that consuming a daily meal with an avocado improved fat distribution as indicated by a lower VS Ratio among female participants. Relative to other adipose tissue depots, VAT accumulation, surrounding internal organs such as the liver, is associated with type 2 diabetes (6, 29, 30), dyslipidemia (31), inflammation, increased risk of thrombosis (32, 33), and nonalcoholic fatty liver disease (34). Therefore, the decrease in VS Ratio among treatment group participants suggests that avocado intake imparts a beneficial abdominal adiposity profile. However, given that these benefits were not observed among males, the robustness of the treatment effect is limited and additional experimental research is needed to further characterize the effects of daily avocado consumption on fat distribution.

TABLE 5 Change in adiposity and glycemic outcomes among adults with overweight or obesity participating in the PATH randomized controlled trial based on sex and group[1]

	Females			Males		
Adiposity outcomes	Control (N = 34)	Treatment (N = 30)	*P*	Control (N = 19)	Treatment (N = 22)	*P*
ΔVAT, g	1.6 ± 89.8	−32.9 ± 81.6*	0.021	−39.7 ± 99.2	−18.1 ± 107.1	0.500
ΔSAAT, g	−61.2 ± 152.7	13.7 ± 133.1*	0.021[2]	−42.4 ± 164.7	22.4 ± 184.2	0.268
ΔVS Ratio	0.117 ± 0.047	−0.015 ± 0.030*	0.001[2]	−0.002 ± 0.046	−0.007 ± 0.057	0.812
Glycemic outcomes	Control (N = 21)	Treatment (N = 16)	*P*	Control (N = 13)	Treatment (N = 14)	*P*
ΔHOMA-IR	−0.02 ± 0.99	0.34 ± 0.89	0.377	0.10 ± 1.0	0.43 ± 0.80	0.332
ΔMatsuda index	−0.47 ± 2.57	−1.12 ± 2.26	0.412	−0.58 ± 2.01	−0.95 ± 1.82	0.615
ΔInsulinogenic index	−0.09 ± 1.49	−0.26 ± 1.28	0.611	−0.48 ± 1.28	0.21 ± 0.93	0.121

[1]Comparison of changes (Δ), using univariate ANOVA following adjustment for changes in energy consumption, in adiposity and glycemic outcomes between participants with overweight and obesity allocated to a group consuming a daily fresh Hass avocado (treatment) compared with a group consuming an isocaloric meal without avocado (control) for 12 wk. Data presented as mean ± SD. *Indicates significant difference in changes (follow-up–post) between groups.
[2]Significance retained following false discovery rate correction.
PATH, *Persea americana* for Total Health; SAAT, subcutaneous abdominal adipose tissue; VAT, visceral adipose tissue; VS Ratio, visceral to subcutaneous abdominal adipose tissue.

The mechanisms by which avocados may contribute to VAT changes are possibly derived from the higher fiber and MUFA content (16). A whole avocado contains ~10 g of total fiber, contributing to ≤40% of the recommendations among females or 30% for males. Greater dietary fiber intake is cross-sectionally associated with lower VAT (35, 36) and related to lower gains in VAT (37). Further, independent of caloric restriction, supplemental fiber intake reduces BMI and waist circumference (38). Dietary fiber, specifically insoluble fiber (contributing to 70% of fiber in an avocado), could affect VAT by increasing fecal bulk and shortening transit time (39), and lowering absorption of nutrients and energy (40). Acutely, meals with higher dietary fiber elicit a moderate postprandial blood glucose response, stimulating a greater sensation of satiety in healthy adults (41). It has also been hypothesized that the elevated postprandial glucose and insulin response can affect macronutrient partitioning in a manner that favors adipose tissue accumulation, and that VAT may be more susceptible to the influence of high insulin responses relative to SAAT (42, 43). There is also evidence that the lipid compositional properties of adipose tissue differentially impact whole body and abdominal obesity (44). The degree of obesity and abdominal distribution of body fat have been negatively correlated with the MUFAs and n−3 PUFA contents of adipose tissue. Given that SFAs were higher and MUFAs were lower in perivisceral than in subcutaneous fat, it is possible that consuming diets that substitute SFAs with MUFAs has the potential to shift abdominal adipose distribution. Indeed, dietary fatty acid intake is known to be an important determinant of changes in adipose tissue composition (45).

Regarding potential clinical or biological relevance of our findings, previous work indicates that inducing a 26% reduction in VAT over the course of 12 mo, using a healthy eating and physical activity/exercise program, corresponds to significant improvement in cardiorespiratory fitness, plasma inflammatory markers, lipid profiles, and OGTT (46). The change in VAT tissue among females in the treatment group in the current study was ~5%; therefore, the change observed in our study was modest. However, considering that the present study was relatively short (3 mo) and did not include an exercise component, the modest change in VAT is not surprising. It is possible that maintaining the treatment regimen over the course of a longer period could have provided the necessary cumulative reduction in VAT to be clinically meaningful. A previous large prospective study observed that annual increases of 3%, 4%, and 3% of VAT, SAAT, and VS Ratio, respectively, were related to an increased risk of diagnosis of diabetes among adults with higher BMI (47). Interestingly, the proportional changes in these measures in the present study were similar in magnitude, albeit the SAAT effects were only observed in the control group. Overall, the changes in abdominal adiposity compartments observed in the present study were modest but could have possible clinical significance if the trajectories for reduction in VAT and VS Ratio were accumulated over a longer period of time. Future longer duration studies are needed to characterize the clinical meaningfulness of these findings.

Interestingly, we observed selective benefits of participating in the intervention for females but not males. This is not entirely surprising since sexual dimorphism in lifestyle interventions targeting obesity have been observed previously (48, 49). Although the explanations for the sexual dimorphism observed in obesity prevalence and differential responses to lifestyle interventions are unclear, recent trends indicate that obesity and extreme obesity prevalence have significantly increased among females, further increasing the need for interventions targeting females. However, additional research that includes equal samples of male participants is necessary to gain a comprehensive understanding of dietary intervention effects. The majority of lifestyle interventions are predominantly comprised of female participants (27% male compared with 73% female) (49), resulting in limited knowledge on dietary implications for adiposity among males. Although the proportions of males (41%) in the present work was greater than most studies, it is possible that we failed to observe significant effects for males due to inadequate sample size of males and/or lower adiposity status of males compared with females at baseline. Given the known differences in adiposity partitioning based on sex, differential effects for adiposity may also have been driven by the fact that the treatment could have contributed to the participants' nutrient recommendations differently. For example, the avocado provided ~51% of Adequate Intake for fiber for females and ~42% for males. Future studies are needed to determine the extent to which dosage impacts changes in adiposity distribution between males and females following avocado consumption.

The present work also examined the implications of daily avocado consumption on insulin resistance, OGTT-derived peripheral insulin sensitivity, and β-cell function. Adding approximately half an avocado to a meal has been shown to increase satiety 4–5 h later and reduce postprandial insulin concentrations (50, 51), suggesting that manipulation of meals with avocado could promote both satiety and metabolic benefits. To our knowledge, the present study represents the first randomized controlled study to examine effects of consuming a whole avocado on glucose and insulin over several months among persons with overweight and obesity. We did not observe significant effects of avocado consumption for glucose and insulin outcomes. Given that VAT and insulin sensitivity and resistance are closely linked, this was a surprising finding. However, it is possible that we did not observe benefits for glycemic outcomes due to the modest reductions in VAT among females only. It is also possible that a longer intervention duration is necessary to observe metabolic benefits for insulin sensitivity following avocado consumption. A limitation of the study was that only a subsample of the participants were able to successfully complete the OGTT procedure. This was primarily due to the invasive nature of the procedure and challenges in successful catheter placement among persons with overweight and obesity (52, 53). Therefore, the findings for OGTT should be interpreted with caution. Nevertheless, these findings are consistent with previous work that examined glycemic responses following several weeks of consuming nutrients found in avocados. Lerman-Garber and colleagues observed that a high MUFA diet was associated with a greater decrease in triglycerides; however, there were no benefits for glycemic measures following a test mixed-meal (28). Although our findings did not support our a priori hypothesis regarding glycemic outcomes, this work suggests that daily consumption of a meal including an avocado, a fruit that is rich in fatty acids, does not detrimentally affect insulin resistance or oral glucose tolerance among adults with overweight and obesity. Additional experiments examining the effects of avocado consumption on glucose and insulin responses is needed to further characterize the effects of avocados on insulin resistance and sensitivity.

In conclusion, consumption of a daily meal with an avocado altered abdominal fat distribution over a 12-wk period.

However, there were no improvements in insulin sensitivity or β-cell function. Future research is necessary to examine the underlying causes of the differential adiposity-related findings based on sex. Given the increasing prevalence of excess adiposity, there is a vital need to develop and test food-based approaches to reducing adiposity as well as improving metabolic health.

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Data Availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

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