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Strawberries decrease atherosclerotic markers in subjects with metabolic syndrome

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Abstract

Strawberries have been reported to be potent antioxidants and reduce cardiovascular risk factors, such as, elevated blood pressure, hyperglycemia, dyslipidemia and inflammation in limited studies. We hypothesized that freeze-dried strawberry supplementation will improve blood pressure, impaired glucose, dyslipidemia, or circulating adhesion molecules in obese subjects with metabolic syndrome, thereby lowering cardiovascular risk factors in these subjects. Twenty-seven subjects with metabolic syndrome [2 males and 25 females; BMI: 37.5±2.15 kg/m^2; age: 47.0±3.0y (means ±SE)] consumed 4 cups freeze-dried strawberry beverage (50g freeze-dried strawberries ~ 3 cups fresh strawberries) or equivalent amounts of fluids (controls, 4 cups water) daily for eight weeks in a randomized controlled trial. Anthropometrics and blood pressure measurements, assessment of dietary intakes and fasting blood draws were conducted at screen and eight weeks of the study. Strawberry supplementation significantly decreased total and LDL-cholesterol [5.8±0.2 to 5.2±0.2 mmol/L, and 3.5±0.2 to 3.1±0.1 mmol/L, respectively, (means ±SE), $p<0.05$] and small LDL-particles using nuclear magnetic resonance-determined lipoprotein subclass profile (NMR-LSP) versus controls at eight weeks [794.6±94.0 to 681.8±86.0 nmol/L, (means ±SE), $p<0.05$]. Strawberry supplementation further decreased circulating levels of vascular cell adhesion molecule-1 (VCAM-1) versus controls at eight weeks [272.7±17.4 to 223.0±14.0 ng/mL, (means ±SE), $p<0.05$). Serum glucose, triglycerides, HDL-cholesterol, blood pressure, and waist circumference were not affected. Thus, short-term freeze-dried strawberry supplementation improved selected atherosclerotic risk factors, including, dyslipidemia and circulating adhesion molecules in subjects with metabolic syndrome and these results need confirmation in future trials.

Keywords

Strawberries; total cholesterol; metabolic syndrome; adhesion molecules

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1. Introduction

Dietary intakes of polyphenolic flavonoids, especially from bran, apples, pears, red wine, grapefruit, strawberries, and chocolate, have been significantly associated with decreased risks for cardiovascular disease (CVD) mortality [1]. Berries, such as, strawberries (*Fragaria* × *ananassa*) are a good source of polyphenolic anthocyanins, fiber, and several micronutrients [2]. Strawberries have been highly ranked as an excellent source of total polyphenols and antioxidant capacity among the fruits and vegetables in US diet [3]. Strawberry supplementation in healthy volunteers has been shown to increase serum antioxidant capacity, thereby indicating protection against oxidative damage [4]. In subjects with cardiovascular risk factors, supplementation of strawberry puree, in combination with other berries has shown to increase HDL-cholesterol and decrease systolic blood pressure versus the control group [5]. These cardio-protective benefits of strawberries have also been supported by observational data from the Iowa Women's Health Study and Women's Health Study, in which strawberry intake was inversely associated with cardiovascular mortality, and C-reactive protein, a biomarker of inflammation, respectively [1,6]. These limited human studies provide intriguing results that need further investigation of cardiovascular effects of strawberries in subjects with metabolic risk factors.

While obesity and metabolic syndrome continue to escalate in the US society [7], there exists a need to identify and administer specific dietary strategies to prevent or reverse these conditions. Metabolic syndrome, comprising of cardiovascular risk factors, including enlarged waist circumference, elevated blood pressure, dyslipidemia (high triglycerides, low HDL), and impaired fasting glucose, is strongly associated with inflammation and atherosclerotic cardiovascular disease [8]. The limited studies reported previously on the health benefits of strawberry or mixed berry intervention in humans, especially in improving blood pressure [5], lipids [5], and inflammation [6], suggest the need of investigating the effects of strawberries on these parameters in subjects with metabolic syndrome. Mechanistic studies using in vitro models provide further evidence on the beneficial effects of strawberries in attenuating hyperglycemia and hypertension, two significant CVD risk factors which coexist in metabolic syndrome [9]. Selected studies using animal models of obesity and dyslipidemia have also shown purified strawberry anthocyanins to normalize dyslipidemia in mice fed a high fat diet [10]. However, no randomized controlled trial has been reported on strawberry supplementation in subjects with metabolic syndrome, which therefore constitutes the scope of our study.

Thus, in this short-term 8-week randomized controlled trial, we tested the hypothesis that freeze-dried strawberry supplementation will improve clinical features of metabolic syndrome associated with atherosclerotic cardiovascular disease. The primary objective was to assess changes in waist circumference, systolic and diastolic blood pressure, serum glucose and lipid profiles including lipoprotein particle size and concentrations, and adhesion molecules, following freeze-dried strawberry (California Strawberry Commission, CA, USA) or control treatment for eight weeks in obese subjects with metabolic syndrome. The results of this study aim to provide evidence of the cardio-protective effects of strawberries at dietary achievable doses in subjects with metabolic syndrome.

2. Methods and materials

2.1. Subjects

Thirty subjects (mean age, 47.0±3.0y, BMI, 37.5±2.15 kg/m^2) with metabolic syndrome [9] were enrolled in the study at the General Clinical Research Center (GCRC) at Oklahoma University Health Sciences Center (OUHSC) and at the Nutritional Sciences (NSCI) Clinical Assessment Unit at Oklahoma State University (OSU). Three subjects dropped on account of

time constraints and 27 subjects completed the study. Subjects were excluded if they were on medications for any chronic disease (cancer, congenital heart disease, diabetes mellitus), or medications known to affect lipid metabolism or possess anti-inflammatory effects, pregnant or lactating, used any form of tobacco products, consumed alcohol on a regular basis, used mega doses of antioxidants or fish oil supplements (> 1g/day), or had any abnormalities in hematology, liver, renal, and thyroid function tests which were confirmed using screening laboratory reports. Subjects were recruited through flyers and e-mail advertisements and were scheduled for a screening blood draw following an initial telephone screen. The 8-week study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the Institutional Review Board at Oklahoma University Health Sciences Center and at Oklahoma State University. Written informed consent was obtained from each subject.

2.2. Study design

This was a randomized controlled trial in which subjects were assigned to the control (4 cups water/day) or strawberry (2 cups strawberry beverage + 2 cups water/day) group for 8 weeks. Subjects were asked to consume 2 cups of strawberry drink per day; since the strawberry beverage is viscous and sticky in consistency, following consumption of each cup of the beverage, subjects were asked to rinse out with another cup of water, thereby amounting to 4 cups of fluid intake per day. All participants in the strawberry group made 3 day (Monday, Wednesday, and Friday) per week visits to drink the first cup in the morning under observation by the research staff and were provided with the remaining supply of the strawberry drink in containers. Subjects were asked to drink the second cup at least six hours later in the day, and were instructed to keep the drink under refrigeration, avoid exposing the drink to direct heat or light or avoid consuming the strawberry drink with any other snack, lunch or dinner. Subjects were asked to bring back any unconsumed or left-over drink to assess unmonitored compliance. The control group was asked to consume 4 cups water per day to ensure similar fluid intake as the strawberry group. Containers were provided to the control participants to measure out 4 cups of water. All subjects were asked to maintain their usual diet and lifestyle throughout the 4-week study, and maintain 3-day food records on a weekly basis. Subjects were also instructed to stay away from all other sources of berries throughout the study period. Subjects were compensated on a weekly basis.

Anthropometric measurements such as, body weight, height, waist circumference, and systolic and diastolic blood pressure were recorded by trained personnel. Fasting blood draws were conducted by a certified phlebotomist on the screening visit (week 0) and at eight weeks of the study. Systolic and diastolic blood pressure was measured in mm Hg using Spot Vital Signs Device (Welch Allyn, Skaneateles Falls, NY). Participants were asked to lie down and relax for approximately 8–10 minutes, following which three blood pressure measurements were recorded at an interval of 5 minutes. Participants were weighed on a flat, uncarpeted surface with the SECA 644 Multifunctional Hand Rail Scale (SECA, Hamburg, Germany) and recorded to the nearest 0.1 kg. Height was measured without shoes, using the Accustat Genentech Stadiometer (San Francisco, CA), and recorded to the nearest 0.1 cm. Waist circumference was measured in subjects at the superior iliac crest using the Gulick II Tape Measure (Vital Signs, Gay Mills, WI).

2.3. Intervention

The freeze-dried strawberry powder was donated by the California Strawberry Commission (Watsonville, CA, USA). Table 1 represents the nutritional composition of 50g freeze-dried strawberries which the subjects received daily for 8 weeks. The freeze-dried strawberry powder was approximately 10% fresh weight of strawberries and had no added ingredients. Subjects received 2 cups strawberry beverage daily for 8 weeks. Each cup had 25g freeze-dried

strawberry powder, one cup water, and one teaspoon vanilla essence. The control subjects were asked to drink 4 cups water on a daily basis in addition to their regular food and beverage intake.

2.4. Biochemical analyses

Freshly drawn blood samples were sent to the OU Medical Center laboratory or the Stillwater Medical Center laboratory for analyses of clinical variables including glucose and lipid profiles using automated diagnostic equipment (Abbott Architect Instruments). Nuclear magnetic resonance-determined lipoprotein subclass profile (NMR-LSP) was performed in first-thaw plasma specimens using a 400-MHz proton NMR analyzer at LipoScience Inc. (Raleigh, NC) as described previously [11]. Plasma ellagic acid was measured using a HPLC-UV procedure previously described by Seeram et al. [12]. Briefly, 500 μL plasma sample was mixed with 2.5 mL acetonitrile and centrifuged at 3500 × g for 10 min. The resulting supernate was evaporated to dryness, residue reconstituted in 100 μL methanol, and 25 μL used as an injection volume. The HPLC system included a 600 pump, 717 Autosampler, 996 Photodiode Array Detector (PDA) and Millennium^{32} Chromatography Software (Waters, USA), and Zorbax C-18 column (Agilent Technologies, Palo Alto, CA). Ellagic acid in samples was eluted at 366 nm, using a flow rate of 0.75 ml/min under gradient conditions using 2% acetic acid in water (solvent A) and 2% acetic acid in methanol (solvent B). Plasma concentrations of soluble intercellular adhesion molecule-1 (sICAM-1) and soluble vascular cell adhesion molecule-1 (sVCAM-1) were determined using ELISA kits (R&D Systems, Inc. Minneapolis, MN) according to the manufacturer's protocol, based on the use of a monoclonal antibody specific for sICAM-1 or sVCAM-1. Briefly in each assay, 100 μL standards, samples (1:20 dilution), and controls were pipetted into the wells and any sICAM-1 or sVCAM-1 present was bound by the immobilized antibody. After washing away any unbound substances, an enzyme-linked monoclonal antibody was added to the wells, followed by a second wash to remove any unbound antibody-enzyme reagent. Substrate solution was added for color development, and the intensity of color was measured at 450 nm, which was proportional to the amount of sICAM-1 or sVCAM-1 initially present in standards, samples and controls. These assays were conducted spectrophotometrically using Synergy HT (BioTek Instruments, Inc. Vermont). The minimum detectable level was 15.625 pg/mL for sICAM-1 and sVCAM-1. The inter-assay CV was 3.51 and 7.59%, respectively.

2.5. Dietary analyses

Three day averages of micro and macronutrient intakes were analyzed using Nutritionist Pro (version 3.2, 2007, Axxya Systems, Stafford, TX). All data entry was performed by Registered Dietitians at GCRC and at NSCI who were trained and certified in using the software. All dietary data entry was verified by a second RD as a measure of quality control. If a participant ate a food that was not in the database, a food with very similar nutrient composition was chosen. Nutrient information was also obtained through food labels or recipes from subjects, online sources, or at grocery stores.

2.6. Statistical analyses

All measures had descriptive statistics calculated and graphs drawn to look for outliers. Outliers due to data errors were corrected where possible or removed. No data points were determined to be outliers. Pair wise differences between strawberry and control groups at baseline were assessed using student t-tests.

Changes in measurements over the eight week study period were assessed by calculating the difference between the pre- and post-intervention measurements. The differences calculated for the strawberry group were then compared to those of the control group using student t-tests. A sample size of 10 in each group was determined to be sufficient to detect a clinically

important difference of 0.5 mmol/L for total cholesterol, 0.3 mmol/L for LDL-cholesterol, 42.6 nmol/L for LDL particle concentration, and 15.5 ng/mL for adhesion molecules (sICAM, sVCAM), with 80% power. This number was increased to 13 per group considering a dropout rate of 20% from the treatment group. All statistical tests were two-tailed with significance level set at 0.05. Significance levels were not adjusted for multiple hypotheses testing, rather, the results were reviewed for consistencies. SPSS for Windows (version 15.0, SPSS Inc., 2006) was used for the statistical calculation and results are presented as means±SE.

3. Results and discussion

3.1. Freeze-dried strawberries

In our study, subjects were supplemented with 50g freeze-dried strawberries, equivalent to 500g fresh strawberries, or approximately 3 cups sliced strawberries daily for eight weeks. Subjects demonstrated active compliance to the strawberry beverage and no significant side effects were noted. We selected our strawberry dose based on previously reported berry interventions that have shown cardiovascular health benefits and compliance with dosing of fresh strawberries ranging from 240g to 454g [4,13,14], or of freeze-dried blueberries (100g) [15,16], in healthy volunteers or those with CVD risk factors. Furthermore, we administered a dose that was within the recommendations of at least 5 cups fruits and vegetables for US adults [17], and provided a concentrated source of polyphenols, fiber, and micronutrients (Table 1) to exert a clinically significant effect in subjects with metabolic syndrome over a period of 8 weeks. Additionally, our intervention also provides some evidence on significant health benefits of freeze-dried strawberries as a novel therapeutic food in CVD management.

For the purpose of commercialization and enhancement of shelf life, fresh strawberries are processed to various products, such as, frozen and dried fruits, jams, jellies, nectars, and juice concentrates. Freeze-drying is a commonly used drying technique shown to significantly retain polyphenols and anthocyanin content of strawberries, in comparison to convection, microwave, or vacuum drying methods [18]. Studies have reported higher total antioxidant activity in freeze-dried strawberries versus fresh or frozen berries [19], and similar or higher total polyphenol and anthocyanin content in freeze-dried versus fresh strawberries [18].

Our study findings of lipid-lowering effects of freeze-dried strawberries conform to previously reported clinical studies showing decreases in lipids with anthocyanin-rich berry extracts in patients with dyslipidemia or metabolic syndrome [20,21]. These findings indicate that anthocyanins in berries may be one of the principal bioactive compounds in improving dyslipidemia. Since anthocyanin content is similar between freeze-dried and fresh strawberries [18], administration of the latter may also produce significant effects on atherosclerotic markers, and warrants further investigation. In our study, freeze-dried strawberries were well tolerated and based on the participants' responses, the intervention was an attractive and convenient mode of obtaining the health benefits of strawberries.

3.2. Lipid profiles

Baseline values of triglycerides, total, LDL-, HDL- and VLDL-cholesterol, and lipoprotein particle size and concentrations were not significantly different between control and strawberry groups. Strawberry supplementation significantly reduced total and LDL-cholesterol levels in our subjects with metabolic syndrome and elevated cholesterol levels. As shown in Table 3, strawberry supplementation caused a 10% decrease in total cholesterol (5.8±0.2 to 5.2±0.2 mmol/L), as well as 11% decrease in LDL-cholesterol (3.5±0.2 to 3.1±0.1 mmol/L) at the end of 8 weeks versus controls. The control group showed a non-significant 2% decrease in total cholesterol (5.5±0.3 to 5.4±0.2 mmol/L) and no change in LDL-cholesterol (3.7±0.3 to 3.7±0.2 mmol/L). Strawberry supplementation did not affect triglycerides, HDL-cholesterol, or VLDL-

cholesterol levels in these subjects. The NMR-based lipid particle concentrations were also shown to be significantly affected by strawberry supplementation. As shown in Table 3, small LDL particle concentrations showed a 14% decrease in strawberry group (794.6±94.0 to 681.8 ±86.0 nmol/L) versus controls which showed a non-significant 5% decrease (799.6±119.7 to 759.6±117.1 nmol/L). No changes were observed in VLDL and HDL particle size and concentrations. Distribution of lipoprotein sub-class profiles, such as variations in concentrations of small, medium and large particles, not reflected in conventional lipid analyses, has been inversely associated with vascular complications in diabetes and atherosclerosis [22,23]. Thus, our data show a significant decrease in small LDL particle concentrations which may contribute to an improved atherogenic profile, following a high dose strawberry intervention, and this needs further investigation in larger trials.

To our knowledge this is the first randomized controlled trial investigating the effects of strawberry supplementation on lipid profiles in subjects with metabolic syndrome. Elevated cholesterol has been significantly associated with the process of atherosclerosis, and a decrease has been associated with an improvement in endothelial function [24]. Though limited, there exists some promising data on the role of strawberries in ameliorating obesity, dyslipidemia, and related metabolic abnormalities. Prior et al. have reported that purified anthocyanins from strawberries added to drinking water prevent the development of dyslipidemia and obesity in mice fed a high-fat diet [10]. Human intervention studies using bilberries and black currant anthocyanin extracts, a combination of berries, cranberry juice or extracts have shown to favorably modulate lipid levels in subjects with dyslipidemia [20], in combined cardiovascular risk factors [5], in healthy [25], or in type 2 diabetic subjects [26], respectively. However, these intervention studies involved berry extracts, juice, or a combination of several berries including strawberries, and therefore the outcomes do not necessarily reflect the effects of consuming a single berry fruit. On the other hand, Jenkins et al. [14] reported no additional effects on lipid levels following a 4-week supplementation of 454g fresh strawberries in hyperlipidemic subjects on a cholesterol-lowering diet. In this case, the effects of high-dose strawberries could have been confounded by the extensive dietary changes made by the participants [14]. Thus, our short-term feeding trial shows the hypocholesterolemic effects of strawberries in un-medicated subjects with metabolic syndrome on usual diet and lifestyle. These findings warrant further investigation in larger dose-response controlled studies.

3.3. Adhesion molecules

In our study, strawberry supplementation significantly decreased plasma levels of vascular cell adhesion molecule-1 (VCAM-1), while no effects were noted in intercellular adhesion molecule-1 (ICAM-1). As depicted in Table 3, strawberry group showed a significant 18% decrease in VCAM-1 levels (272.7±17.4 to 223.0±14.0 ng/mL) at eight weeks in comparison to controls, which showed a non-significant 1.6% decrease (312.6±59.2 to 307.5±44.1 ng/mL). Circulating levels of adhesion molecules, such as, ICAM-1 and VCAM-1 have shown to be elevated in subjects with metabolic syndrome and have been positively correlated with CVD [27]. Elevated cholesterol has also been shown to increase expressions of adhesion molecules in an animal model of atherosclerosis [28]. The role of berries in decreasing adhesion molecules has not been well investigated. Ruel et al. reported a significant decrease in adhesion molecules (ICAM-1 and VCAM-1) in healthy volunteers following a 12-week supplementation of cranberry juice cocktail [29]. In our study strawberries decreased VCAM-1 levels, thereby causing a decrease in the surrogate marker of atherosclerosis in subjects with metabolic syndrome. These findings support the previously reported observational data on the cardiovascular health benefits of strawberries in women [1,6].

3.4. Metabolic syndrome

In our study, no effects were observed on features of metabolic syndrome following strawberry intervention for eight weeks. As noted in Table 2, our study subjects had clinically significant obesity (BMI > 35), and a greater number of subjects were on anti-hypertensive medications in the control group (24%) versus none in the strawberry intervention. The number of multivitamin users were greater in the strawberry (53%) versus control group (8%), and effects on lipids and adhesion molecules remained significantly different when data were analyzed without multivitamin users in the strawberry and control groups. Waist circumference, systolic and diastolic blood pressure, fasting glucose, triglycerides, and HDL-cholesterol were not affected in the strawberry or control group (Table 3). There is emerging evidence on the role of strawberries in attenuating features of metabolic syndrome based on mechanistic and limited clinical trials. Cheplick et al. [9] reported the role of specific strawberry cultivars in significantly inhibiting α-glucosidase activity and angiotensin-1-converting enzyme (ACE) activity using in vitro models. In a postprandial study in healthy volunteers, Torronen et al. showed the effects of a berry meal, including strawberries, in significantly decreasing postprandial rise of glucose versus controls [30]. Erlund et al. [5] have also reported the anti-hypertensive and HDL-raising effects of strawberries, as part of a mixed berry intervention, in subjects with existing cardiovascular risk factors. However, we observed no change in components of metabolic syndrome following a high dose strawberry supplementation, which may be explained by the short duration of the study, normal glucose or mildly elevated triglycerides in our subjects at baseline, or the possibility that strawberries may act synergistically with other berries or bioactive compounds in significantly reversing these features of metabolic syndrome, which was not investigated in our study.

3.5. Nutrient intakes and Compliance

No significant differences in dietary intakes were observed in the strawberry or control group at eight weeks of the study. As noted in Table 4, participants' mean intakes of antioxidant micronutrients, especially vitamins C (42.0±12.6 mg) and E (2.7±0.8 mg) were significantly below the dietary reference intakes at the beginning and end of the study [31]. This indicates poor food choices, especially of food groups high in micronutrients, such as, fruits, vegetables, and whole grains in subjects with metabolic syndrome. Ellagic acid, a biochemical measure of compliance was shown to be significantly elevated in 13 out of 15 subjects in the strawberry group (15.2±5.2ng/mL, means±SE), while no detectable levels were noted in the control group.

Thus, our study findings support the working hypothesis that freeze-dried strawberry supplementation decreases selected atherosclerotic risk factors, such as, total and LDL-cholesterol, small LDL-particle concentrations and circulating sVCAM-1 associated with metabolic syndrome. However, strawberry supplementation did not significantly affect features identified in the criteria of metabolic syndrome [8], namely, waist circumference, elevated blood pressure, impaired fasting glucose, and dyslipidemia (high triglycerides and low HDL), over the 8-week period. Certain limitations of our study include a small sample size, consisting primarily of women, and also the absence of a dose-response design. Also, our study lacked a control group matched for calorie and/or fiber intake which may be more appropriate in identifying the health benefits of bioactive compounds in strawberries. Finally, since freeze-dried strawberries are not commercially available in grocery stores, the practical relevance of our findings needs to be further confirmed in an intervention using fresh or frozen strawberries in subjects with metabolic syndrome. In summary, this short-term study shows the cardio-protective benefits of freeze-dried strawberries in selectively improving biomarkers of atherosclerosis associated with metabolic syndrome and CVD. Thus, our study provides some evidence for the dietary inclusion of strawberries as a preventive measure in metabolic syndrome and CVD.

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Abbreviations

NMR-LSP	nuclear magnetic resonance-determined lipoprotein subclass profile
VCAM-1	vascular cell adhesion molecule-1
ICAM-1	intercellular adhesion molecule-1
CVD	cardiovascular disease
GCRC	General Clinical Research Center
OUHSC	Oklahoma University Health Sciences Center
OSU	Oklahoma State University
NSCI	Nutritional Sciences
HPLC-UV	high pressure liquid chromatography-ultraviolet
LDL	low-density lipoprotein
VLDL	very low-density lipoprotein
HDL	high-density lipoprotein
ACE	angiotensin-1 converting enzyme

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Table 1

Nutrient composition of freeze-dried strawberry powder

	Per 50g[a]
Carbohydrates (g)	33.0
Protein (g)	3.5
Fat (g)	0.5
Calories (kcal)	150.0
Moisture (%)	10.0
Ash (g)	3.17
Vitamin C (mg)	109.0
Total Phenolics (mg)[b]	2006.0
Total Anthocyanins (mg)[c]	154.0
Phytosterols (mg)	50.0
Total dietary fiber (%)	8.0

[a] 10% fresh weight; California Strawberry Commission (Watsonville, CA, USA). Subjects received 50g/day ~ 500g or 3 cups fresh strawberries.

[b] expresssed as mg gallic acid equivalents.

[c] expressed as mg cyanidin-3-glucoside equivalents.

Table 2

Baseline characteristics of study participants

	Control	Strawberry
N	12	15
Age (years)	45.0±3.0	48.0±5.3
BMI (kg/m^2)	36.4±3.0	39.0±2.0
M/F	2/10	0/15
AST (U/L)	26.7±3.2	25.7±2.0
ALT (U/L)	34.8±6.9	30.0±3.0
BUN (mg/dL)	11.3±1.1	13.0±1.0
Creatinine (mg/dL)	0.8±0.1	0.9±0.03
Total Bilirubin (mg/dL)	0.7±0.04	0.5±0.04
Hemoglobin (g/dL)	13.5±0.3	13.7±0.2
Anti-hypertensive medication users (%)	24.0	0*
Multivitamin users (%)	8.0	53.0*

Data were analyzed by Student *t* test and are shown as means ± SEM.

*Significantly different between control and strawberry groups at baseline or 0 week ($P<0.05$).

Table 3

Changes in anthropometrics, blood pressure, glucose and lipid profiles, and adhesion molecules between control and strawberry intervention groups

Variables	Control (n=12)		Strawberry (n=15)	
	0 week	8 week	0 week	8 week
Body weight (kg)	102.7±6.6	103.2±6.6	102.0±3.0	102.6±2.6
Waist circumference (inches)	42.5±1.9	42.2±1.7	43.0±2.3	44.0±3.2
Systolic blood pressure (mm Hg)	130.0±2.6	127.3±2.6	135.0±3.7	134.5±3.4
Diastolic blood pressure (mm Hg)	80.0±2.1	80.3±2.6	85.0±3.2	84.2±2.5
Glucose (mmol/L)	5.0±0.2	4.8±0.2	5.2±0.2	5.1±0.1
Total cholesterol (mmol/L)	5.5±0.3	5.4±0.2	5.8±0.2	5.2±0.2*
HDL-cholesterol (mmol/L)	1.1±0.1	1.0±0.04	1.2±0.1	1.2±0.04
LDL-cholesterol (mmol/L)	3.7±0.3	3.7±0.2	3.5±0.2	3.1±0.1*
VLDL-cholesterol (mmol/L)	1.1±0.1	1.0±0.1	1.0±0.2	1.0±0.1
Triglycerides (mmol/L)	1.5±0.2	1.6±0.4	1.6±0.5	1.6±0.4
Large VLDL &Chylomicron particles (nmol/L)	6.2±1.65	5.5±1.40	9.1±2.3	7.0±1.5
Medium VLDL particles (nmol/L)	23.7±5.21	22.0±5.50	32.2±5.0	34.5±5.5
Small VLDL particles (nmol/L)	35.3±7.0	29.1±3.70	27.4±2.5	33.3±3.3
Large LDL particles (nmol/L)	335.7±83.8	382.9±62.7	403.5±60.0	463.6±36.2
IDL particles (nmol/L)	148.7±20.5	127.4±25.8	131.3±24.3	117.9±20.0
Small LDL particles (nmol/L)	799.6±119.7	759.6±117.1	794.6±94.0	681.8±86.0*
Large HDL particles (μmol/L)	4.1±0.6	4.3±0.5	3.8±0.3	4.0±0.3
Medium HDL particles (μmol/L)	10.7±1.1	11.3±1.1	11.9±1.5	10.5±1.3
Small HDL particles (μmol/L)	19.0±1.14	18.4±1.6	19.9±1.4	22.1±0.9
VLDL mean particle size (nm)	51.0±3.2	52.0±2.6	53.0±1.8	51.2±1.4
LDL mean particle size (nm)	20.4±0.2	21.0±0.3	20.8±0.2	21.0±0.2
HDL mean particle size (nm)	9.1±0.1	9.1±0.1	9.0±0.1	9.0±0.1
ICAM-1 (ng/mL)	316.9±27.0	293.1±26.1	294.0±16.8	265.4±15.7
VCAM-1 (ng/mL)	312.6±59.2	307.5±44.1	272.7±17.4	223.0±14.0*

Subjects with metabolic syndrome were supplemented with freeze-dried strawberries (4 cups beverage) or 4 cups water (controls). Their body weight, waist circumference, systolic and diastolic blood pressure, fasting glucose, triglycerides, TC, HDL-, LDL-, and VLDL-cholesterol, lipoprotein particle concentrations and size, and adhesion molecules were measured on day 0 and 8 weeks of the study. Data were analyzed by Student *t* test and are shown as means ± SEM.

*Significantly different between control and strawberry groups at 8 weeks ($P<0.05$).

Table 4

Dietary intakes of subjects

Variables	Control (n=12)		Strawberry (n=15)	
	0 week	8 week	0 week	8 week
Energy (kcal)	1850.8±37.5	1935.6±50.4	1900.3±148.3	1842.7±109.1
Carbohydrates (g)	230.7±39.0	218.3±28.9	222.2±32.6	214.0±23.0
Proteins (g)	65.8±18.5	63.7±39.5	71.7±15.1	70.0±16.2
Total fats (g)	75.8±28.5	78.5±32.6	81.5±14.0	72.4±8.1
Saturated fats (g)	21.5±3.9	18.5±5.7	24.4±4.6	22.6±2.5
Monounsaturated fats (g)	23.6±13.5	19.1±6.4	20.3±4.4	17.0±3.5
Polyunsaturated fats (g)	10.6±3.2	13.2±4.2	12.1±2.7	10.5±2.1
Dietary fiber (g)	15.6±3.7	12.5±3.2	17.2±3.9	15.0±3.0
Vitamin A (IU)	2389.7±375.0	2456.5±412.0	2485.7±618.0	2851.4±583.7
Vitamin E (mg)	3.2±0.7	2.8±0.9	2.5±0.9	2.2±0.6
Vitamin C (mg)	45.6±13.6	39.5±12.8	43.6±16.7	37.8±7.3

Dietary intakes of macro- and micronutrients, and fiber in control and strawberry intervention groups at 0 and 8 weeks of the study. Data were analyzed by Student *t* test and are shown as means ± SEM. Control vs. strawberry, not significant for any variable at 8 weeks.