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Green Tea Catechin Consumption Enhances Exercise-Induced Abdominal Fat Loss in Overweight and Obese Adults[1,2]

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Abstract

This study evaluated the influence of a green tea catechin beverage on body composition and fat distribution in overweight and obese adults during exercise-induced weight loss. Participants (n = 132 with 107 completers) were randomly assigned to receive a beverage containing ~625 mg of catechins with 39 mg caffeine or a control beverage (39 mg caffeine, no catechins) for 12 wk. Participants were asked to maintain constant energy intake and engage in ≥180 min/wk moderate intensity exercise, including ≥3 supervised sessions per week. Body composition (dual X-ray absorptiometry), abdominal fat areas (computed tomography), and clinical laboratory tests were measured at baseline and wk 12. There was a trend ($P = 0.079$) toward greater loss of body weight in the catechin group compared with the control group; least squares mean (95% CI) changes, adjusted for baseline value, age, and sex, were −2.2 (−3.1, −1.3) and −1.0 (−1.9, −0.1) kg, respectively. Percentage changes in fat mass did not differ between the catechin [5.2 (−7.0, −3.4)] and control groups [−3.5 (−5.4, 1.6)] ($P = 0.208$). However, percentage changes in total abdominal fat area [−7.7 (−11.7, −3.8) vs. −0.3 (−4.4, 3.9); $P = 0.013$], subcutaneous abdominal fat area [−6.2 (−10.2, −2.2) vs. 0.8 (−3.3, 4.9); $P = 0.019$], and fasting serum triglycerides (TG) [−11.2 (−18.8, −3.6) vs. 1.9 (−5.9, 9.7); $P = 0.023$] were greater in the catechin group. These findings suggest that green tea catechin consumption enhances exercise-induced changes in abdominal fat and serum TG. J. Nutr. 139: 264–270, 2009.

Introduction

It is estimated that over 72 million adults in the United States are overweight or obese (1). Excess adiposity, and particularly excess abdominal fat, increases the risk of morbidity from a number of health conditions, including hypertension, heart disease, and diabetes, and is also associated with greater risk for certain cancers (2).

Green tea catechins have been suggested to have antiobesity effects. Experiments in rodent models demonstrated that tea catechins produced acute increases in fat oxidation (3–5) and reduced dietary fat-induced weight gain (5). In humans, a green tea extract containing a mixture of catechin polyphenols and caffeine significantly increased 24-h energy expenditure and reduced 24-h respiratory quotient, indicating an increase in the ratio of fat:carbohydrate oxidized (6).

Tea catechins may have favorable effects on body composition in humans. In a 12-wk study in overweight males, consumption of a higher dose (483 mg/d) of tea catechins compared with a lower dose (118.5 mg/d) was associated with significantly greater reductions in body weight, body fat, and visceral fat area (7). In a 12-wk study of 240 Japanese men and women with increased visceral adiposity, consumption of a beverage providing 583 mg/d of tea catechins was associated with significantly greater reductions in body weight, body fat, and abdominal fat mass compared with a control beverage providing 96 mg/d (8). As reviewed by Wolfram (9), similar results have been seen in other trials, although not all studies have shown benefits with regard to changes in body weight and fat relative to control groups (10–13). Therefore, additional investigation is needed to more clearly define the influences of green tea catechin consumption on body composition and abdominal adiposity. The present study was designed to evaluate the effects of a green tea catechin-containing beverage on body composition and fat distribution in overweight and obese adults in the United States during exercise-induced weight loss.

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Materials and Methods

Study design. This was a randomized, double-blind, controlled clinical trial conducted in accordance with Good Clinical Practice Guidelines, the Declaration of Helsinki (2000), and US 21 Code of Federal Regulations. The study was conducted at 2 clinical research sites, Provident Clinical Research (Bloomington, IN) and Meridien Research (St Petersburg, FL), and included a 2-wk screening period followed by 12 wk of treatment. An institutional review board (Schulman Associates IRB, Cincinnati, OH) approved the protocol before initiation of the study and subjects provided written informed consent before any study procedures were performed.

Participants. Participants included generally healthy, normally sedentary men and women. Pregnant or lactating women (or those planning to become pregnant during the study) were excluded. Eligible participants were required to be 21–65 y old, have a waist circumference ≥87 cm (women) or ≥90 cm (men), and total cholesterol (total-C)[7] ≥5.2 mmol/L at screening. Subjects agreed to consume no more than 2 caffeinated beverages per day, not including the study product, and no over-the-counter supplements or medications containing caffeine were allowed. Subjects were asked to avoid consuming brewed tea and catechin-containing foods and dietary supplements during the study.

Volunteers with a BMI <25.0 kg/m^2 or ≥40.0 kg/m^2; recent weight loss of >4.5 kg; recent use of any weight loss medications, supplements, or programs; a history of weight-reducing surgery; or an eating disorder were excluded. Subjects completed a physical activity readiness questionnaire at screening (14). If there was any indication from the questionnaire or from laboratory or baseline exercise test results suggesting that regular, unsupervised physical activity was inadvisable, the participant was not enrolled.

Study beverage and food intake. Eligible participants were randomly assigned to receive either 500 mL/d of a beverage providing ~625 mg catechins or a control beverage (**Table 1**). Both the active and control beverages contained water, sodium chloride, artificial citrus flavoring, glucose, erythritol, and sucralose. Each 500-mL serving provided 63 kJ (15 kcal) of energy and 250 mg of sodium. The catechin beverage also contained green tea extract and the placebo beverage contained added caffeine to match the caffeine content of the catechin beverage (~39 mg). Study beverages were packaged in identical, single-serving containers. The study products were labeled and coded in such a manner that subjects and staff were unaware of which product each participant was receiving. The beverages had similar sensory characteristics. Internal pretrial testing showed no difference in preference or palatability ratings between the active and control beverages. Subjects were instructed to consume 1 500-mL bottle per day within 30 min, at any time of the day, with or without food. Subjects recorded their daily consumption of the study beverage and any other caffeinated beverages.

Participants were asked to maintain their habitual energy intake during the study. Three-day diet records were collected at baseline and at 6 and 12 wk and analyzed to evaluate consistency of energy intake. Analyses were completed with the Food Processor Nutrition Analysis and Fitness Software (version 8.5.0, ESHA Research).

Exercise testing and intervention. At baseline and wk 12, participants underwent maximal treadmill graded exercise testing using the United States Air Force protocol (15). The day following randomization, participants began an exercise program modeled after that used in the Diabetes Prevention Program (16). Participants were instructed to increase their activity level, with a goal of achieving ≥180 min/wk of moderate-intensity physical activity, and to attend at least 3 supervised exercise sessions per week. Pedometer readings were recorded before and after each supervised session. A physical activity score was calculated as described by Sallis et al. (17) from the Stanford 7-d Physical Activity Recall questionnaire completed by participants at baseline and at 6 and 12 wk.

TABLE 1 Catechin content of the test beverages

Catechin polyphenols	Control	Catechin
	mg/500 mL serving	
Gallocatechin	0	51.8
Epigallocatechin	0	207.5
Catechin	0	19.2
Epicatechin	0	53.9
EGCG	0	214.4
Gallocatechin gallate	0	15.4
Epicatechin gallate	0	56.5
Catechin gallate	0	6.0
Total catechin	0	624.7

Anthropometric, blood pressure, and body composition measurements. Body weight and waist circumference were measured at each study visit. Waist circumference was measured on a horizontal plane at the level of the iliac crest using a nonstretch anthropometric tape at the end of a normal expiration (18).

Resting blood pressure was assessed at each clinic visit after the subject had been seated for 3 min. Subjects refrained from ingesting caffeine, including the study beverage, during the 30 min preceding the measurement. Blood pressure was measured using either a standard manual mercury sphygmomanometer or an automatic blood pressure device with an appropriate-sized cuff (bladder within the cuff must have encircled ≥80% of the arm). Two measurements were taken, each separated by 2 min. If these differed by >5 mm Hg (systolic and/or diastolic), an additional reading was obtained after 2 min. The 2 or 3 readings obtained were averaged for each visit.

Dual energy X-ray absorptiometry (DXA) and abdominal computed tomography (CT) scans were performed at baseline and wk 12. Whole-body DXA scans were performed with the GE Healthcare LUNAR. Fat mass and fat-free mass were determined utilizing Prodigy Advance DXA System software, version 9.30 (Bloomington, IN) and version 9.0 (St. Petersburg, FL). CT scans were performed at the Bloomington, IN site on a Seimens Somatom and at the St. Petersburg, FL site on a Highspeed GE spiral. Three-slice abdominal CT scans were taken at the level of the lumbar 4–5 vertebrae utilizing a slice thickness of ≤7 mm. The measurement protocol and central reading of the CT scan data were completed by Bio-Imaging Technologies using a standard protocol as described elsewhere (19).

Laboratory measurements. Biochemical measurements were conducted by Medpace Reference Laboratories and the USDA Human Nutrition Research Center on Aging at Tufts University [malondialdehyde (MDA) only] on blood samples from fasting subjects. Serum total-C and triglyceride (TG) concentrations were measured using Roche reagents on a Roche Modular instrument. Serum HDL-cholesterol (HDL-C) was measured by photometry after precipitation of apolipoprotein B containing lipoproteins with Mg-dextran sulfate. The serum LDL-cholesterol (LDL-C) concentration was calculated according to the Friedewald equation (20): LDL-C = total-C – HDL-C – TG/2.2. LDL-C was not calculated when the TG concentration was >4.5 mmol/L.

Fasting insulin was measured by chemiluminescence on a Roche Elecsys and fasting glucose using photometry on a Roche Modular instrument. Plasma high-sensitivity C-reactive protein (hs-CRP) was measured on a Siemens Medical Solutions BN II nephelometer. Serum FFA and β-hydroxybutyrate were analyzed using WACO and Randox reagents, respectively, on the Randox Daytona. Whole blood glycosylated hemoglobin (HbA_{1c}) was measured by HPLC on a Tosoh Bioscience G7. Plasma MDA was measured by reverse-phase HPLC according to Volpi and Tarugi (21), in which a thiobarbituric acid-MDA conjugate derivative was injected onto a C18 column and fluorometri-

[7] Abbreviations used: CT, computed tomography; DXA, dual energy X-ray absorptiometry; HbA_{1c}, glycosylated hemoglobin; HDL-C, HDL-cholesterol; hs-CRP, high-sensitivity C-reactive protein; LDL-C, LDL-cholesterol; MDA, malondialdehyde; MET, metabolic equivalent; TG, triglyceride; total-C, total cholesterol.

cally quantified at an excitation of 515 nm and emission of 553 nm. MDA concentration was calculated from calibration curves of authentic standard, with a linear relationship and $R^2 > 0.995$.

Statistical analyses. Statistical analyses were conducted using SAS version 9.1.3. All tests for significance were performed at $\alpha = 0.05$, 2-sided. An evaluable sample of 88 subjects was expected to provide 80% power ($\alpha = 0.05$, 2-sided) to detect a least-squares mean difference in response of 3.7% (pooled SD of 6.1%) in fat mass between treatment groups.

The main analyses of outcome variables were completed on a modified intent-to-treat sample, defined as all subjects who were randomized, consumed at least 1 serving of study product, and provided at least 1 postrandomization blood sample. If a value was missing, the previous nonbaseline value was carried forward to the subsequent visit.

Differences in response by treatment center were investigated and no material differences were observed, so data from the 2 clinics were pooled for analysis. The assumption of normality of residuals was investigated for each response variable. Some deviations from normality were noted. However, because analyses using nonparametric procedures produced results that were not materially different from those using parametric models, only the latter are presented. For continuous variables, least squares means and SEM or 95% CI are presented.

Treatment groups were compared at baseline using chi-square tests or ANCOVA (covariates included age and sex). Changes or percentage changes from baseline to 12 wk in body weight, waist circumference, DXA and CT measurements, physical activity, exercise test, and biochemical variables were evaluated by ANCOVA. All models for continuous variables were adjusted for baseline value, age, and sex. The frequencies of adverse events were compared between groups using chi-square or Fisher's exact tests. Values in the text are least square means and SEM unless noted otherwise.

Results

Participants and demographics. Of the 337 participants screened, 132 were randomly assigned to the 2 treatment groups. Four participants (2 in each group) did not return for the wk 2 visit. Thus, the study sample discussed herein included 128 participants, 21 of whom did not complete the study. One participant in the catechin group discontinued because of a serious adverse event (hospitalization due to elevated blood pressure), 6 participants withdrew consent, 3 participants were withdrawn due to protocol violations, and 11 participants discontinued for other reasons, mainly loss to follow-up (**Fig. 1**).

Demographic and baseline characteristics were similar for both groups (**Table 2**). DXA and CT measurements were also similar for both groups at baseline, with the exception of intra-abdominal fat area, which was larger ($P = 0.019$) in the control group than in the catechin group. The mean age of the study sample was ~48 y. Most subjects were of non-Hispanic white race/ethnicity (91%), and approximately one-half were male (catechin, 49.2%; control, 55.6%). The mean BMI was ~32 kg/m^2. Baseline characteristics did not differ between randomized subjects who did and did not complete the treatment period (data not shown).

Study beverage compliance. Mean compliance with study beverage consumption, based on participant interview and counting of unused servings, was similar for both treatment groups ($P = 0.103$). Overall, 97% of participants in the catechin group and 92% of participants in the control group were at least 90% compliant with study beverage consumption.

Physical activity and exercise tests. Physical activity was similar for both groups throughout the study. At baseline, the physical activity score was 219.4 ± 8.5 metabolic equivalent (MET)-hours in the catechin group and 225.4 ± 8.6 MET-hours in the control group ($P = 0.623$). Groups did not differ ($P = 0.595$) in the change from baseline: 12.3 ± 8.0 MET-hours (catechin group) and 6.1 ± 8.4 MET-hours (control). Exercise test durations at baseline were longer in the catechin group (10.9 ± 0.4 min) than in the control group (9.9 ± 0.4 min) ($P = 0.041$). Changes from baseline to wk 12 did not differ between the catechin (2.2 ± 0.3 min) and control (2.1 ± 0.3 min) groups ($P = 0.840$).

Dietary intake. Based on analysis of 3-day diet records, the catechin and control groups did not differ in dietary variables at baseline or in the changes from baseline to wk 12 in energy intake or any nutrient variables (data not shown). Prior to randomization, caffeine intakes were 115.3 ± 15.2 mg/d in the catechin group and 115.2 ± 15.6 mg/d in the control group ($P = 0.997$). At wk 12, changes from baseline in caffeine intakes (excluding the study beverages) did not differ between the catechin group (−3.3 ± 31.7 mg/d) and the control group (−6.7 ± 33.9 mg/d) ($P = 0.943$).

Body weight and waist circumference. The catechin group tended ($P = 0.079$) to have greater loss of body weight compared with the control group at wk 12 (**Fig. 2**). Changes in waist circumference did not differ significantly (data not shown).

Body composition and abdominal fat areas. The catechin and control groups did not differ in the percentage changes in fat mass ($P = 0.208$) or intra-abdominal fat area ($P = 0.125$) (**Fig. 3**). However, both total abdominal fat area ($P = 0.013$) and abdominal subcutaneous fat area ($P = 0.019$) had decreased more at wk 12 in the catechin group.

Serum lipids and FFA and plasma hs-CRP and MDA. TG ($P = 0.023$) and FFA ($P = 0.038$) had decreased more at wk 12 in the catechin group than in the control group (**Table 3**). Groups did not differ at wk 12 in the changes from baseline in total-C, LDL-C, or HDL-C (Table 3). At baseline, the catechin and control groups did not differ in serum concentrations of hs-CRP (3.93 ± 0.48 vs. 3.92 ± 0.49 mmol/L; $P = 0.982$), MDA (0.76 ± 0.05 vs. 0.76 ± 0.05 μmol/L; $P = 0.970$), or β-hydroxybutyrate (0.17 ± 0.04 vs. 0.13 ± 0.05 mmol/L; $P = 0.556$). At wk 12, β-hydroxybutyrate, hs-CRP, or MDA responses did not differ between the 2 groups (data not shown).

Glucose homeostasis. At baseline, the catechin group and control groups did not differ in fasting glucose (5.6 ± 0.07 vs. 5.7 ± 0.07 mmol/L; $P = 0.144$), fasting insulin [92.7 ± 10.9 vs. 86.0 (11.1) pmol/L; $P = 0.671$]; and HbA_{1c} (5.4 ± 0.04 vs. 5.4 ± 0.04%, $P = 0.781$). None of the responses for glucose homeostasis variables differed significantly at wk 12 (data not shown).

Safety and tolerability. The frequencies of adverse events of any kind were similar for the catechin (66.7%) and control (71.4%) groups ($P = 0.574$). The most common adverse events were joint pain (catechin, $n = 6$; control, $n = 9$), rhinitis (catechin, $n = 5$; control, $n = 5$), and sinusitis (catechin, $n = 8$; control, $n = 2$). The majority of adverse events were considered by the investigator to be of mild or moderate intensity and unlikely to be related to the study product. Two adverse events, a tooth disorder experienced by 1 participant in the catechin group and tachycardia experienced by 1 control participant,

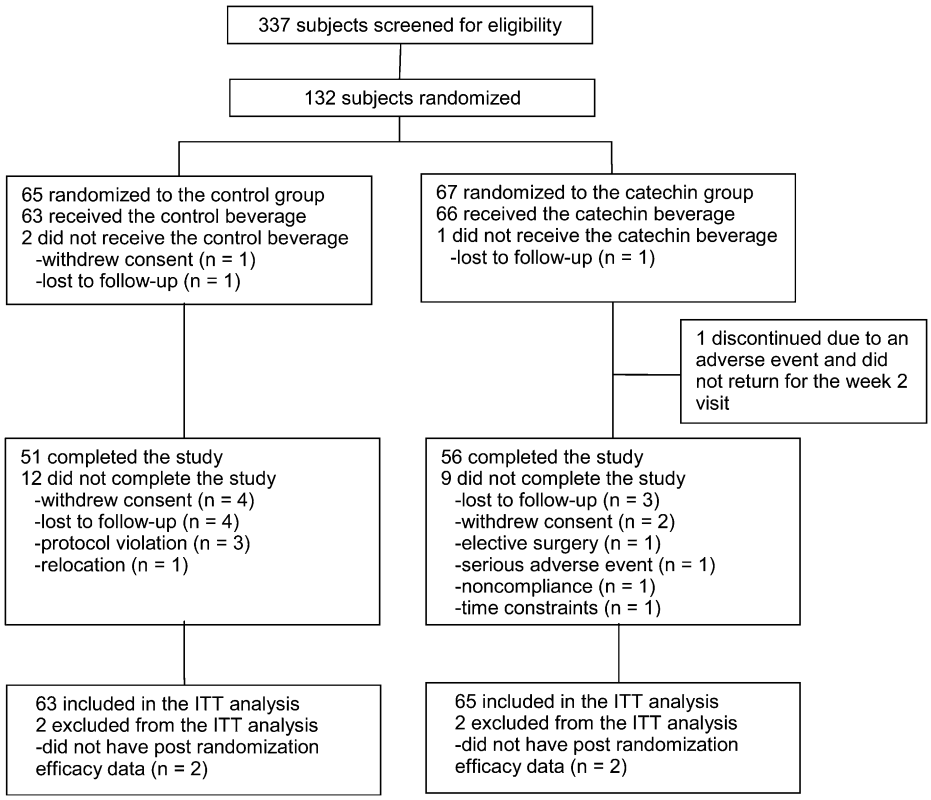

FIGURE 1 Disposition of subjects. Other reasons for discontinuation included elective surgery (catechin group, $n = 1$), time constraints (catechin group, $n = 1$), and subject relocating (control group, $n = 1$). ITT, Intent to treat.

were considered severe. Both events were judged by the investigator as probably not related to the study product. A total of 14 adverse events, 5 in catechin participants (dyspepsia, 3 cases of hypertension, and elevated liver enzymes) and 9 in control participants (constipation, elevated liver enzymes, 3 cases of hypertension, nausea, pain, palpitation, and ulcerative stomatitis) were judged by the investigator as possibly related to the study product (prior to breaking the treatment code).

One participant in the catechin group reported a serious adverse event (hospitalization due to elevated blood pressure). The participant discontinued participation in the study but returned for the final study visit, at which time his systolic and diastolic blood pressures were controlled with medication.

The frequencies of abnormal laboratory values were similar between groups and there was no evidence of liver toxicity. Despite a higher pulse rate in control participants at baseline ($P = 0.008$), pulse rate was generally stable and similar in both groups throughout the study. At wk 12, neither systolic nor diastolic blood pressure responses differed significantly between groups (data not shown).

TABLE 2 Demographic and baseline characteristics of subjects in the intent-to-treat sample by treatment group[1]

Characteristic	Control	Catechin	*P*
n	63	65	
Gender			
Male, *n* (%)	35 (55.6)	32 (49.2)	0.474
Female, *n* (%)	28 (44.4)	33 (50.8)	
Race/ethnicity			
Non-Hispanic White, *n* (%)	58 (92.1)	59 (90.8)	0.649
African American, *n* (%)	2 (3.2)	4 (6.2)	
Hispanic, *n* (%)	2 (3.2)	2 (3.1)	
Other, *n* (%)	1 (1.6)	0 (0.0)	
Age, *y*	49.0 ± 1.3	47.0 ± 1.3	0.263
BMI, kg/m^2	32.2 ± 0.5	32.2 ± 0.5	0.987
Weight, *kg*	95.1 ± 1.7	95.1 ± 1.7	0.990
Height, *cm*	171.5 ± 0.8	171.3 ± 0.8	0.827
Waist circumference, *cm*	108.9 ± 1.3	108.2 ± 1.3	0.675
n	62[2]	65	
Total fat mass, *kg*	38.1 ± 1.1	37.0 ± 1.1	0.464
Fat-free mass, *kg*	55.7 ± 0.9	56.7 ± 0.9	0.388
n	61[2]	63[2]	
Abdominal fat area, cm^2	397.8 ± 15.2	385.9 ± 14.8	0.578
Intra-abdominal fat area, cm^2	91.2 ± 5.2	74.0 ± 5.0	0.019
Abdominal subcutaneous fat area, cm^2	306.6 ± 13.3	311.9 ± 13.0	0.776

[1] Values are least squares means ± SEM or *n* (%).
[2] Some participants did not have 2 valid DXA and/or CT scans accounting for the lower number of subjects.

Discussion

In this study, our aim was to evaluate the effects of a beverage containing green tea catechins (625 mg/d) and caffeine (~39 mg/d), compared with a caffeine-matched, catechin-free control beverage, on body composition in overweight and men and women during exercise-induced weight loss. The group receiving the catechin-containing beverage tended to have greater weight loss, significant reductions in total and subcutaneous abdominal fat areas, and significant reductions in serum TG and FFA concentrations.

To our knowledge, only 1 small previous study has evaluated the influence of tea catechin consumption on exercise-induced changes in body weight and composition. Hill et al. (12) studied 38 overweight and obese women who exercised at a moderate intensity for 45 min, 3 times per week for 12 wk, while consuming 300 mg of epigallocatechin gallate (EGCG) or placebo daily in capsule form. EGCG typically accounts for

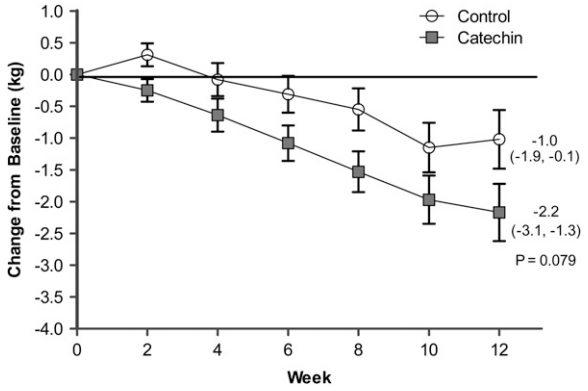

FIGURE 2 Changes from baseline to wk 2, 4, 6, 8, 10, and 12 in body weight of overweight or obese adults who consumed a control or catechin-containing beverage. Values are least squares means ± SEM, $n = 65$ (catechin) and 63 (control). Values were adjusted for baseline value, age, and sex. Values to the right of wk 12 data are least squares means (95% CI).

approximately one-third of the catechin content of green tea (12). They found that EGCG consumption did not significantly alter the effects of exercise training on body weight or composition. The current study was larger and included both men and women with increased abdominal adiposity. Subjects consumed 625 mg/d of mixed green tea catechins that included 214 mg of EGCG.

Green tea catechins may influence body composition through a number of mechanisms, although effects on thermogenesis and altering substrate oxidation have been those most studied in humans (9,22,23). Catechins have been shown to enhance energy expenditure and fat oxidation in animals, putatively through inhibition of catechol-*O*-methyl-transferase, an enzyme that degrades norepinephrine, thereby prolonging the action of sympathetically released norepinephrine (9,23). Published data from studies in humans are limited, but in aggregate, the results

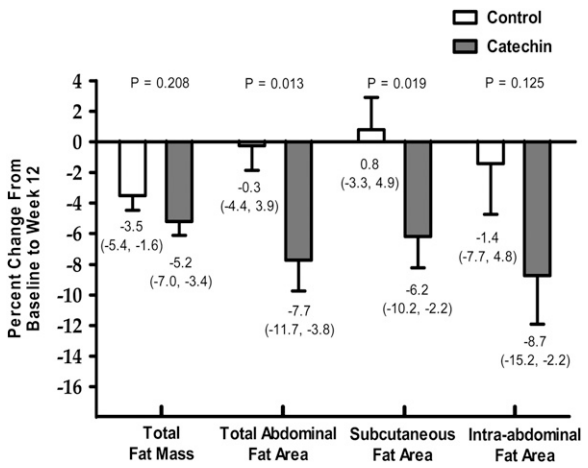

FIGURE 3 Percent changes from baseline (least squares mean ± SEM and 95% CI) to wk 12 in total fat mass, and total abdominal, abdominal subcutaneous, and intra-abdominal fat areas by treatment group ($n = 57$ and 52 for fat mass and 55 and 51 for abdominal fat areas in the catechin and control groups, respectively). Values below bars are least squares means (95% CI). Values are adjusted for baseline value, age, and sex.

TABLE 3 Baseline concentrations and changes from baseline in serum lipids and FFA in overweight or obese adults who consumed a control or catechin-containing beverage for 12 wk[1]

Variable	Control	Catechin	*P*
TG, *mmol/L*			
Baseline	2.0 ± 0.1	1.7 ± 0.1	0.082
From baseline, %	1.9 ± 4.0	−11.2 ± 3.9	0.023
Total-C, *mmol/L*			
Baseline	5.8 ± 0.1	5.7 ± 0.1	0.498
From baseline, %	−2.4 ± 1.2	−5.3 ± 1.2	0.089
LDL-C, *mmol/L*			
Baseline	3.6 ± 0.1	3.6 ± 0.1	0.516
From baseline, %	−2.8 ± 1.6	−4.0 ± 1.6	0.591
HDL-C, *mmol/L*			
Baseline	1.35 ± 0.04	1.29 ± 0.04	0.253
From baseline, %	−2.8 ± 1.3	−3.2 ± 1.3	0.813
FFA, *mmol/L*			
Baseline	0.47 ± 0.02	0.43 ± 0.02	0.239
From baseline, *mmol/L*	0.02 ± 0.02	−0.05 ± 0.02	0.038

[1] Values are least squares means ± SEM, $n = 63$ (control) or 65 (catechin) at baseline and ranged from 52 to 57 (control) and from 57 to 58 (catechin) for changes from baseline to wk 12.

suggest that consumption of tea catechins (375–612 mg/d from oolong tea, green tea, or green tea extract) with caffeine (150–270 mg/d) may modestly (3–4%) increase 24-h energy expenditure (6,24,25).

One study did not show enhanced 24-h energy expenditure or fat oxidation with EGCG at doses of 270, 600, 900, and 1200 mg, each with 600 mg caffeine (26). The effects of caffeine and catechins may be additive to a point, but the dose of caffeine employed by these investigators may have been high enough that catechins could not enhance the responses.

Both groups in the present study received ~39 mg/d caffeine in the study beverages and background intakes of caffeine did not differ between the groups. Caffeine intakes during the treatment period were roughly 154 mg/d in both groups, which is within the range (150–270 mg/d) reported for studies in which catechin (375–612 g/d) and caffeine consumption was associated with increases of 3–4% in 24-h energy expenditure (6,24,25). The additional fat loss observed in the catechin group of 0.6 kg or 1.7% ($P = 0.208$) was not significant, so it cannot be reliably separated from random variation. However, this represents a difference in energy balance of ~252 kJ (60 kcal)/d. Therefore, our results are not inconsistent with the possibility that catechin consumption increases energy expenditure to a degree that could produce clinically important changes in body fat over time. Larger and/or longer trials will be needed to test this hypothesis.

Tea catechins (with caffeine) have been shown to increase fat oxidation, particularly during the postprandial period, as indicated by a reduced respiratory quotient during indirect calorimetry (6,22,25). The increase in fat oxidation may be due primarily to greater sympathetically activated hepatic fat oxidation (5,27). It is possible that enhanced fat oxidation contributed to the reduced levels of TG and FFA in the present study, although these were measured after an overnight fast, when any effect from prior catechin consumption would be expected to have been minimal. Therefore, we think that the greater reductions in these variables in the catechin group are more likely to be secondary to reduced abdominal fat storage.

The sympathetic nervous system is thought to play a role in regional differences in mobilization of lipid from adipose depots (28). Therefore, it is possible that catechins, by enhancing sympathetic effects, might have differential influences on lipid storage in various fat depots. Findings from studies in animals suggest that mesenteric and hepatic fat accumulation are markedly reduced by catechin (and caffeine) feeding (29,30). The results from the present trial, as well as limited data from prior studies in humans (8,31,32), support the view that catechin consumption may enhance reductions in abdominal fat.

Greater abdominal fat loss, as observed in this trial, is of particular interest, because excess abdominal adiposity is an important risk factor for cardiovascular disease (33). Intraabdominal (visceral) fat has the highest rate of TG turnover and excess visceral adiposity is the most closely related to metabolic disturbances, particularly insulin resistance and hypertriglyceridemia (34). Upper body subcutaneous fat is the next most active and lower body subcutaneous fat has the lowest rate of TG turnover; therefore, excess lower body subcutaneous fat is the least metabolically adverse (34). In the postabsorptive state, expanded adipocytes release a greater quantity of fatty acids into the circulation. Higher circulating levels of FFA increase hepatic synthesis and secretion of TG-rich VLDL (35). Accordingly, it is not surprising that the reduced abdominal adiposity in the catechin beverage group was accompanied by reductions in fasting FFA and TG concentrations.

Tea catechins have been found to lower plasma cholesterol in animal models (36,37) and to inhibit oxidation of LDL-C (38,39). Reductions in total and LDL-C have been reported with consumption of tea catechins in humans (7,8,40). The lack of difference in MDA response between the groups in the present study suggests that catechin consumption did not inhibit lipid peroxidation. Total and lipoprotein cholesterol responses also did not differ between groups in the current study. Therefore, the results of the present study do not support the beneficial effects on blood lipids and lipid peroxidation reported by some previous investigators.

The catechin beverage employed was well tolerated. The frequencies of adverse events overall and for the major body systems, including abnormal laboratory values, were similar for participants in the catechin and control beverage groups.

In summary, the findings of this study suggest that consumption of a beverage containing green tea catechins (625 mg/d) may enhance exercise-induced loss of abdominal fat and improve circulating FFA and TG levels. Additional research is warranted to further clarify the mechanisms responsible for these effects.

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Literature Cited

1. Ogden CL, Carroll MD, McDowell MA, Flegal KM. Obesity among adults in the United States: no change since 2003–2004. NCHS data brief no 1. Hyattsville (MD): National Center for Health Statistics. 2007.
2. NIH. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: the evidence report. Obes Res. 1998;6 Suppl 2:S51–209.
3. Onizawa K, Watanabe H, Yamaguchi T, Osaki N, Harada U, Tokimitsu I, Shimasaki H, Itakura H. Effect of tea catechins on the oxidation of dietary lipids in rats. J Oleo Sci. 2001;50:657–62.
4. Osaki N, Harada U, Watanabe H, Onizawa K, Yamaguchi T, Tokimitsu I, Shimasaki H, Itakura H. Effect of tea catechins on energy metabolism in rats. J Oleo Sci. 2001;50:677–82.
5. Murase T, Nagasawa A, Suzuki J, Hase T, Tokimitsu I. Beneficial effects of tea catechins on diet-induced obesity: stimulation of lipid catabolism in the liver. Int J Obes Relat Metab Disord. 2002;26:1459–64.
6. Dulloo AG, Duret C, Rohrer D, Girardier L, Mensi N, Fathi M, Chantre P, Vandermander J. Efficacy of a green tea extract rich in catechin polyphenols and caffeine in increasing 24-h energy expenditure and fat oxidation in humans. Am J Clin Nutr. 1999;70:1040–5.
7. Hase T, Komine Y, Meguro S, Takeda Y, Takahashi H, Matsui F, Inaoka S, Katsuragi Y, Tokimitsu, et al. Anti-obesity effects of tea catechins in humans. J Oleo Sci. 2001;50:599–605.
8. Nagao T, Hase T, Tokimitsu I. A green tea extract high in catechins reduces body fat and cardiovascular risks in humans. Obesity (Silver Spring). 2007;15:1473–83.
9. Wolfram S, Wang Y, Thielecke F. Anti-obesity effects of green tea: from bedside to bench. Mol Nutr Food Res. 2006;50:176–87.
10. Kovacs EM, Lejeune MP, Nijs I, Westerterp-Plantenga MS. Effects of green tea on weight maintenance after body weight loss. Br J Nutr. 2004;91:431–7.
11. Diepvens K, Kovacs EM, Nijs I, Vogels N, Westerterp-Plantenga MS. Effect of green tea on resting energy expenditure and substrate oxidation during weight loss in overweight females. Br J Nutr. 2005;94:1026–34.
12. Hill AM, Coates AM. Can EGCG reduce abdominal fat in obese subjects? J Am Coll Nutr. 2007;26:S396–402.
13. Hsu CH, Tsai TH, Kao YH, Hwang KC, Tseng TY, Chou P. Effect of green tea extract on obese women: a randomized, double-blind, placebo-controlled clinical trial. Clin Nutr. 2008;27:363–70.
14. American College of Sports Medicine. ACSM's health/fitness facility standards and guidelines. 2nd ed. Champaign (IL): Human Kinetics; 1997.
15. Wolthuis RA, Froelicher VF, Fischer J. New practical treadmill protocol for clinical use. Am J Cardiol. 1977;39:697–700.
16. The Diabetes Prevention Program (DPP) Research Group. The Diabetes Prevention Program (DPP): description of lifestyle intervention. Diabetes Care. 2002;25:2165–71.
17. Sallis JF, Haskell WL, Wood PD, Fortmann SP, Rogers T, Blair SN, Paffenbarger RS Jr. The physical activity assessment methodology in the five-city project. Am J Epidemiol. 1985;121:91–106.
18. Adult Treatment Panel III. Third report of the national cholesterol education program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (adult treatment panel III) final report. Circulation. 2002;106:3143–421.
19. Pesce M. Provident PRV06001 Project plan. Newton (PA): Bio-Imaging Technologies; 2006.
20. Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clin Chem. 1972;18:499–502.
21. Volpi N, Tarugi P. Improvement in the high-performance liquid chromatography malondialdehyde level determination in normal human plasma. J Chromatogr B Biomed Sci Appl. 1998;713:433–7.
22. Boschmann M, Thielecke F. The effects of epigallocatechin-3-gallate on thermogenesis and fat oxidation in obese men: a pilot study. J Am Coll Nutr. 2007;26:S389–95.
23. Kao YH, Chang HH, Lee MJ, Chen CL. Tea, obesity, and diabetes. Mol Nutr Food Res. 2006;50:188–210.
24. Komatsu T, Nakamori M, Komatsu K, Hosoda K, Okamura M, Toyama K, Ishikura Y, Sakai T, Kunii D, et al. Oolong tea increases energy metabolism in Japanese females. J Med Invest. 2003;50:170–5.
25. Rumpler W, Seale J, Clevidence B, Judd J, Wiley E, Yamamoto S, Komatsu T, Sawaki T, Ishikura Y, et al. Oolong tea increases metabolic rate and fat oxidation in men. J Nutr. 2001;131:2848–52.
26. Berube-Parent S, Pelletier C, Dore J, Tremblay A. Effects of encapsulated green tea and guarana extracts containing a mixture of epigallocatechin-3-gallate and caffeine on 24 h energy expenditure and fat oxidation in men. Br J Nutr. 2005;94:432–6.
27. Dulloo AG, Seydoux J, Girardier L, Chantre P, Vandermander J. Green tea and thermogenesis: interactions between catechin-polyphenols, caffeine, and sympathetic activity. Int J Obes Relat Metab Disord. 2000;24:252–8.
28. Bartness TJ, Bamshad M. Innervation of mammalian white adipose tissue: implications for the regulation of total body fat. Am J Physiol. 1998;275:R1399–411.
29. Bose M, Lambert JD, Ju J, Reuhl KR, Shapses SA, Yang CS. The major green tea polyphenol, (-)-epigallocatechin-3-gallate, inhibits obesity,

metabolic syndrome, and fatty liver disease in high-fat-fed mice. J Nutr. 2008;138:1677–83.
30. Ito Y, Ichikawa T, Morohoshi Y, Nakamura T, Saegusa Y, Ishihara K. Effect of tea catechins on body fat accumulation in rats fed a normal diet. Biomed Res. 2008;29:27–32.
31. Nagao T, Meguro S, Soga S, Otsuka A, Tomonobo K, Fumoto S, Chikama A, Mori K, Yuzawa M, et al. Tea catechins suppress accumulation of body fat in humans. J Oleo Sci. 2001;50:717–28.
32. Nagao T, Komine Y, Soga S, Meguro S, Hase T, Tanaka Y, Tokimitsu I. Ingestion of a tea rich in catechins leads to a reduction in body fat and malondialdehyde-modified LDL in men. Am J Clin Nutr. 2005;81:122–9.
33. Stunkard AJ. Current views on obesity. Am J Med. 1996;100:230–6.
34. Després JP. Intra-abdominal obesity: an untreated risk factor for Type 2 diabetes and cardiovascular disease. J Endocrinol Invest. 2006;29:77–82.
35. Reaven G. Syndrome X past, present, and future. In: Draznin B, Rizza R, editors. Clinical research in diabetes and obesity. 2nd vol. Totowa (NJ): Humana Press; 1997. p. 357–82.
36. Chan PT, Fong WP, Cheung YL, Huang Y, Ho WKK, Chen ZY. Jasmine green tea epicatechins are hypolipidemic in hamsters (Mesocricetus auratus) fed a high fat diet. J Nutr. 1999;129:1094–101.
37. Yang M, Wang C, Chen H. Green, oolong and black tea extracts modulate lipid metabolism in hyperlipidemia rats fed high-sucrose diet. J Nutr Biochem. 2001;12:14–20.
38. Ishikawa T, Suzukawa M, Ito T, Yoshida H, Ayaori M, Nishiwaki M, Yonemura A, Hara Y, Nakamura H. Effect of tea flavanoid supplementation on the susceptibility of low-density lipoprotein to oxidative modification. Am J Clin Nutr. 1997;66:261–6.
39. Osada K, Takahashi M, Hoshina S, Nakamura M, Nakamura S, Sugano M. Tea catechins inhibit cholesterol oxidation accompanying oxidation of low density lipoprotein in vitro. Comp Biochem Physiol C Toxicol Pharmacol. 2001;128:153–64.
40. Unno T, Tago M, Suzuki Y, Nozawa A, Sagesaka YM, Kakuda T, Egawa K, Kondo K. Effect of tea catechins on postprandial plasma lipid responses in human subjects. Br J Nutr. 2005;93:543–7.