A Green Tea Extract High in Catechins Reduces Body Fat and Cardiovascular Risks in Humans

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Abstract

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Objective: The body fat reducing effect and reduction of risks for cardiovascular disease by a green tea extract (GTE) high in catechins was investigated in humans with typical lifestyles.

Research Methods and Procedures: Japanese women and men with visceral fat-type obesity were recruited for the trial. After a 2-week diet run-in period, a 12-week double-blind parallel multicenter trial was performed, in which the subjects ingested green tea containing 583 mg of catechins (catechin group) or 96 mg of catechins (control group) per day. Randomization was stratified by gender and body mass index at each medical institution. The subjects were instructed to maintain their usual dietary intake and normal physical activity.

Results: Data were analyzed using per-protocol samples of 240 subjects (catechin group; $n = 123$, control group; $n = 117$). Decreases in body weight, body mass index, body fat ratio, body fat mass, waist circumference, hip circumference, visceral fat area, and subcutaneous fat area were found to be greater in the catechin group than in the control group. A greater decrease in systolic blood pressure (SBP) was found in the catechin group compared with the control group for subjects whose initial SBP was 130 mm Hg or higher. Low-density lipoprotein (LDL) cholesterol was also decreased to a greater extent in the catechin group. No adverse effect was found.

Discussion: The continuous ingestion of a GTE high in catechins led to a reduction in body fat, SBP, and LDL cholesterol, suggesting that the ingestion of such an extract contributes to a decrease in obesity and cardiovascular disease risks.

Key words: tea polyphenol, adiposity, serum cholesterol, blood pressure, metabolic syndrome

Introduction

Tea is traditionally used as a medication based on experience, and the physiological activities of components of tea have been extensively described in Asian countries, mainly in Japan and China.

Green tea contains catechins, a class of low molecular weight polyphenols that consist mainly of flavan-3-ol monomers; catechins are present mainly as catechin (C),[1] catechin gallate (CG), gallocatechin (GC), gallocatechin gallate (GCG), epicatechin (EC), epicatechin gallate (ECG), epigallocatechin (EGC), and epigallocatechin gallate (EGCG). Green tea leaves normally contain 10% to 20% catechins, mainly EGCG (1). Numerous studies of catechins' antioxidant and anti-cancer action and their preventive effects on ischemic heart disease have attracted a great deal of attention (2).

The effects of catechins on energy and fat metabolism have recently been examined in humans. Dulloo et al. reported that the ingestion of 270 mg/d of EGCG increased energy expenditure and lipid oxidation in 10 subjects (3). Chantre et al. reported that ingestion of 375 mg/d of cat-

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[1] Nonstandard abbreviations: C, catechin; CG, catechin gallate; GC, gallocatechin; GCG, gallocatechin gallate; EC, epicatechin; ECG, epicatechin gallate; EGC, epigallocatechin; EGCG, epigallocatechin gallate; GTE, green tea extract; SBP, systolic blood pressure; DBP, diastolic blood pressure; TFA, total fat area; VFA, visceral fat area; SFA, subcutaneous fat area; T-cho, serum total cholesterol; HDL-cho, serum high-density lipoprotein cholesterol; LDL-cho, low-density lipoprotein cholesterol; Glc, plasma glucose; GOT, glutamic-oxaloacetic transaminase; GPT, glutamic-pyruvic transaminase; γ-GTP, γ-glutamyl transferase.

Table 1. Catechins and caffeine content of the test beverages

	Units of measure	Control beverage (% of total catechins)	GTE beverage high in catechins (% of total catechins)
Total catechins	mg/100 mL	28.3 (100.0)	171.4 (100.0)
Catechin	mg/100 mL	1.8 (6.3)	12.6 (7.3)
Catechin gallate	mg/100 mL	1.3 (4.8)	11.8 (6.9)
Gallocatechin	mg/100 mL	7.0 (24.6)	37.5 (21.9)
Gallocatechin gallate	mg/100 mL	7.1 (25.2)	41.1 (24.0)
Epicatechin	mg/100 mL	1.4 (4.8)	9.5 (5.5)
Epicatechin gallate	mg/100 mL	1.5 (5.3)	9.1 (5.3)
Epigallocatechin	mg/100 mL	3.3 (11.6)	20.4 (11.9)
Epigallocatechin gallate	mg/100 mL	4.9 (17.4)	29.5 (17.2)
Caffeine	mg/100 mL	22.1	21.3
Total catechins/can	mg/340 mL	96.3	582.8
Caffeine/can	mg/340 mL	75.0	72.3

GTE, green tea extract.

echins tended to decrease waist circumference in 70 subjects (4). In a previous study, we demonstrated that the ingestion of 690 mg/d of catechins reduced body fat in 35 men (5). Almost all of these trials, however, were conducted either on a small-scale ($n < 100$), or under a hypocaloric diet, or were gender-biased. Therefore, the present trial was conducted to clarify the body fat reducing effect of the continuous ingestion of a green tea extract (GTE) high in catechins in more than 200 Japanese women and men who were maintaining their usual lifestyles. We also examined the effects of a GTE high in catechins on risk factors of cardiovascular disease.

Research Methods and Procedures

Design and Subjects

This trial was performed during the period of April 2002 to August 2002 on volunteers at seven medical institutions in the Kanto District in Japan. The protocol was approved by the institutional review board at the Center of Health Examination of Isogo Central & Neurosurgical Hospital. The trial was conducted in accordance with the Helsinki Declaration under the supervision of clinical investigators. The subjects provided informed consent, including their permission for the findings to be published.

Japanese women and men ($n = 270$) 25 to 55 years of age with a BMI of 24 to 30 kg/m^2 and/or a waist circumference of 80 to 94 cm who were considered to be visceral fat-type obese, but had not been treated at an outpatient department and had no serious liver or renal disease, were recruited for the trial.

This was a randomized double-blind, controlled parallel multicenter trial consisting of a 2-week run-in period and a 12-week treatment period. After the run-in period, the subjects were allocated into two groups designated as the control group (ingestion of control beverage) and the catechin group (ingestion of GTE beverage high in catechins). Randomization was stratified by gender and BMI measured at the time of the run-in period at each institution (control group, 56 women and 79 men; catechin group, 58 women and 77 men).

The subjects consumed one can (340 mL) of the test beverage each day for a 12-week period. The time of ingestion of the test beverage was not limited, but it was recommended that the subjects drink the test beverage within 1 hour of their evening meal to maintain compliance. Energy and fat intake was not limited throughout the trial period, but supplemental food products or medications known to influence lipid or carbohydrate metabolism were prohibited. Tea and coffee were not limited throughout the trial period. The subjects were instructed to maintain their usual dietary intake and physical activity.

The subjects visited the medical institution at 4-week intervals after the run-in period. Eating and drinking, except for water, were prohibited from 9:00 PM on the day before the visit until the various measurements were completed.

Anthropometry, measurements of circulatory parameters, fasting blood sampling for biochemical and hematologic parameters, and interviews were performed at Week −2, Week 0, Week 4 Week 8, and Week 12. Computed tomography was performed at Week 0 and 12 to measure the abdominal fat area.

Table 2. Changes in dietary content and beverages after drinking either a GTE beverage high in catechins or a control beverage for 12 weeks (catechin group, $n = 123$; control group, $n = 117$)

	Catechin/control	Week 0	Week 12
Energy intake (MJ/d)	Catechin	8.03 (1.63)	7.78 (1.74)
	Control	7.93 (1.52)	7.96 (1.52)
Fat intake (g/d)*	Catechin	61.9 (16.9)	58.9 (16.9)
	Control	59.8 (15.9)	57.9 (15.4)
Fat energy ratio (%/d)*†	Catechin	28.6 (4.3)	28.1 (4.7)
	Control	28.2 (5.4)	27.0 (5.3)
Tea intake (mL/d)‡	Catechin	108.5 (172.4)	98.7 (152.7)
	Control	86.1 (137.6)	87.9 (184.0)
Coffee intake (mL/d)*	Catechin	117.4 (130.3)	95.2 (111.5)
	Control	140.8 (156.5)	117.8 (130.0)
Tannin intake (mg/d)§			
From tea	Catechin	67.0 (108.6)	54.4 (85.6)
	Control	57.2 (89.3)	60.4 (150.2)
From coffee*	Catechin	70.5 (75.8)	54.7 (69.1)
	Control	83.5 (90.3)	67.2 (77.8)
Caffeine intake (mg/d)§			
From tea	Catechin	26.9 (40.4)	24.0 (37.6)
	Control	22.1 (31.6)	22.8 (64.4)
From coffee*	Catechin	47.0 (50.6)	36.5 (46.1)
	Control	55.6 (60.2)	44.8 (51.9)

GTE, green tea extract. Values are mean (standard deviation). Data are averages of 5 days of dietary diary records.
* There was a time effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
† Fat energy was calculated as 1 g = 37.674 kJ.
‡ Tea intake was the sum of green tea, oolong tea, and black tea intakes except the test beverage.
§ Tannin intake was the sum of green tea, oolong tea, and black tea. Caffeine intake was the sum of teas and coffee except the test beverage. The initial values were not signficantly different between groups.

Test Substance

We used brewed green tea with a natural flavor as the base beverage, and a GTE beverage high in catechins and a control beverage were prepared by adding two types of GTE powder containing different amounts of catechins and caffeine. The base beverage was prepared by extracting 9 g of green tea leaves with 1 L of distilled water at 80 °C for 5 minutes. The catechins and caffeine contents per 100 g were 33.0 and 5.4 g, respectively, for one type of GTE powder and 85.6 and 0.0 g, respectively, for the other. The GTE beverage high in catechins was prepared by adding GTE powders to the base beverage to give ~600 mg of catechins/340 mL and 70 mg of caffeine/340 mL. The control beverage was prepared similarly to give ~100 mg of catechins/340 mL and 70 mg of caffeine/340 mL. The canned beverages were sterilized at 138 °C for 30 seconds. The C, CG, GC, GCG, EC, ECG, EGC, EGCG, and caffeine contents of each test beverage are shown in Table 1.

Anthropometry and Measurement of Circulatory Parameters

Height (only at Week −2), body weight, body fat ratio, waist circumference, and hip circumference were measured at each visit. BMI was calculated from the height and body weight, and body fat mass and lean body mass were calculated from the body weight and body fat ratio. Body fat ratio was measured by bioelectrical impedance analysis using a body fat meter TF-770 (Omron Co., Kyoto, Japan). The circumference at the umbilical level was measured as the waist circumference, and the maximal gluteal circumference was measured as the hip circumference. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and pulse rate were measured using a mercury manometer with subjects in a seated position after resting quietly for 10 minutes.

Evaluation of the Abdominal Fat Level

The abdominal fat level, total fat area (TFA), visceral fat area (VFA), and subcutaneous fat area (SFA) were mea-

Table 3. Changes in anthropometric values after drinking either a GTE beverage high in catechins or a control beverage for 12 weeks (catechin group, $n = 123$; control group, $n = 117$)

	Catechin/control	Week 0	Week 4	Week 8	Week 12	Δ Value at Week 12*
Body weight (kg)†‡§	Catechin	73.3 (9.7)	72.5 (9.8)	72.2 (9.8)	71.6 (9.8)	−1.7 (1.5)
	Control	72.1 (10.0)	71.9 (10.1)	71.9 (10.2)	72.1 (10.3)	−0.1 (1.7)
BMI (kg/m^2)†‡§	Catechin	26.9 (1.9)	26.6 (1.9)	26.4 (1.9)	26.2 (1.9)	−0.6 (0.6)
	Control	26.7 (2.1)	26.6 (2.2)	26.6 (2.2)	26.6 (2.2)	−0.0 (0.6)
Body fat ratio (%)†‡§	Catechin	30.7 (6.4)	30.0 (5.8)	28.9 (6.3)	28.3 (6.1)	−2.5 (3.3)
	Control	30.7 (5.4)	30.2 (5.7)	29.2 (5.6)	30.0 (5.6)	−0.7 (2.8)
Body fat mass (kg)†‡§	Catechin	22.3 (4.6)	21.6 (4.0)	20.6 (4.1)	20.0 (4.0)	−2.3 (2.6)
	Control	22.1 (4.4)	21.6 (4.7)	20.9 (4.6)	21.5 (4.7)	−0.5 (2.3)
Lean body mass (kg)‡	Catechin	51.0 (9.4)	50.9 (9.3)	51.5 (9.8)	51.6 (9.7)	0.6 (2.3)
	Control	50.1 (8.6)	50.3 (8.6)	51.0 (8.9)	50.5 (8.8)	0.4 (2.3)
Waist circumference (cm)†‡§	Catechin	87.2 (5.2)	86.3 (5.3)	85.5 (5.5)	84.7 (5.5)	−2.5 (2.2)
	Control	86.5 (6.1)	86.4 (6.5)	86.6 (6.8)	86.5 (6.7)	0.0 (2.5)
Hip circumference (cm)†‡§	Catechin	98.0 (4.7)	97.2 (4.5)	96.3 (4.4)	95.7 (4.4)	−2.3 (2.0)
	Control	97.2 (5.6)	97.0 (5.9)	97.1 (6.0)	97.1 (6.0)	−0.1 (2.4)
Total fat area (cm^2)†‡§	Catechin	324.3 (79.3)			308.4 (79.9)	−16.0 (46.6)
	Control	315.8 (77.1)			316.0 (79.0)	0.1 (32.6)
Visceral fat area (cm^2)†‡§	Catechin	109.2 (42.3)			98.9 (38.6)	−10.3 (23.3)
	Control	107.7 (44.0)			103.8 (38.9)	−3.9 (24.9)
Subcutaneous fat area (cm^2)†§	Catechin	215.2 (66.9)			209.5 (66.3)	−5.7 (38.5)
	Control	208.1 (60.7)			212.1 (64.9)	4.0 (24.8)

GTE, green tea extract. Values are mean (standard deviation).
* The value is the change from Week 0 to Week 12. The initial values were not significantly different between groups.
† There was a treatment-by-time interaction effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
‡ There was a time effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
§ There was a significant difference between the groups in the Δ value at Week 12, as determined using an unpaired t test (two-sided, $p < 0.05$).

sured from computed tomography images using a PC software, Fat Scan, version 2 (N2 System Co., Osaka, Japan), developed according to the method reported by Tokunaga et al. (6). An image of the cross section at the L4/L5 intervertebral disc level was obtained under X-ray conditions of a tube voltage of 120 kVp and 200 to 250 mA, and the film was processed at a window level of 0 and a width of 1000.

Biochemical and Hematologic Parameter Analysis

The concentrations of serum triacylglycerol (enzymatic method after eliminating endogenous free glycerol), serum total cholesterol (T-cho; cholesterol oxidase method), serum high-density lipoprotein cholesterol (HDL-cho; selective inhibition method), serum low-density lipoprotein cholesterol [LDL-cho; enzymatic method (7)], serum free fatty acid (enzymatic method), and plasma glucose (Glc; glucose-dehydrogenase method) were determined in fasting blood samples.

To confirm the safety of the test beverage, glutamic-oxaloacetic transaminase (GOT; standardization-adjusted ultraviolet method), glutamic-pyruvic transaminase (GPT; standardization-adjusted ultraviolet method), γ-glutamyl transferase (γ-GTP; L-glutamyl-3-carboxy-4-nitroanilide substrate method), lactate dehydrogenase (Wroblewski-La-Due method), and alkaline phosphatase (p-nitrophenyl phosphate substrate method) were measured in fasting blood samples. The levels of these enzymes were determined by standard methods established by the Japan Society of Clinical Chemistry (8). In addition, white blood cells, red blood cells, hemoglobin, hematocrit, and platelet count were measured using a hematocytometer.

Table 4. Changes in circulatory parameters after drinking either a GTE beverage high in catechins or a control beverage for 12 weeks

	Catechin/ control	*n*	Week 0	Week 4	Week 8	Week 12	Δ Value at Week 12*
Systolic blood pressure (mm Hg)	Catechin	123	127.0 (14.8)	126.2 (14.7)	127.0 (15.2)	124.3 (14.2)	−2.7 (13.6)
	Control	117	128.8 (14.3)	128.7 (14.5)	127.9 (13.7)	128.8 (15.1)	0.0 (12.0)
Initial <130 mm Hg (mm Hg)†	Catechin	67	116.3 (9.8)	118.9 (10.9)	120.3 (13.8)	119.0 (12.9)	2.7 (12.5)
	Control	56	117.4 (10.0)	120.5 (10.2)	122.7 (11.2)	120.6 (13.1)	3.1 (11.4)
Initial ≥130 mm Hg (mm Hg)†‡§	Catechin	56	139.8 (7.9)	134.9 (13.8)	135.0 (12.8)	130.8 (13.0)	−9.0 (12.1)
	Control	61	139.3 (8.6)	136.3 (13.8)	132.8 (14.0)	136.4 (12.7)	−2.9 (12.0)
Diastolic blood pressure (mm Hg)	Catechin	123	76.9 (10.4)	77.2 (10.5)	77.7 (9.9)	75.8 (9.1)	−1.1 (9.8)
	Control	117	77.9 (9.2)	78.3 (9.7)	77.7 (10.1)	77.1 (10.1)	−0.8 (7.9)
Initial <85 mm Hg (mm Hg)†	Catechin	93	72.6 (7.8)	73.5 (8.5)	75.3 (9.1)	73.3 (8.2)	0.7 (10.1)
	Control	88	73.9 (6.6)	75.3 (8.4)	75.0 (8.8)	74.3 (9.0)	0.4 (7.7)
Initial ≥85 mm Hg (mm Hg)†	Catechin	30	90.3 (4.6)	88.6 (7.6)	85.0 (8.7)	83.5 (7.5)	−6.7 (6.4)
	Control	29	90.0 (3.4)	87.3 (7.2)	85.6 (9.6)	85.5 (8.5)	−4.5 (7.6)
Pulse rate (beats/min)†	Catechin	123	73.6 (5.9)	73.5 (6.5)	75.1 (7.9)	74.2 (6.4)	0.6 (6.9)
	Control	117	73.5 (5.8)	73.2 (6.8)	75.3 (6.6)	75.4 (6.8)	1.9 (6.0)

GTE, green tea extract. Values are mean (standard deviation).
* The value is the change from Week 0 to Week 12. The initial values were not significantly different between groups.
† There was a time effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
‡ There was a treatment-by-time interaction effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
§ There was a significant difference between the groups in the Δ value at Week 12, as determined using an unpaired *t* test (two-sided, $p < 0.05$).

All biochemical and hematologic parameters were measured in laboratories at each medical institution or a subcontracted clinical laboratory testing facility.

Dietary Diary and Daily Living Records

The subjects recorded the content of their meals in a dietary diary for 5 days before the visits at Week 0 and Week 12. Based on the information in the diary, dieticians analyzed the daily energy intake, fat intake, fat energy ratio, tea and coffee intake, and tannin and caffeine intake from tea and coffee using the fourth Revised Standard Tables of Food Composition in Japan (9), and the mean values for the 5 days were calculated. Tea intake was the sum of green tea, oolong tea, and black tea. All values were calculated excluding the test beverages.

In addition, the subjects recorded the intake of the test beverage, and daily activities, including eating habits and exercise, for 3 days of each week in a daily living record using a simple checklist. The clinical investigators provided feedback of the daily living record to the subjects to encourage keeping a constant level of daily activity.

Interviews

Physical conditions and adverse effects were examined by a physician in the interview at each visit.

Statistical Analysis

The values of all test parameters are presented as the mean ± standard deviation. Results were expressed either in actual values or changes from Week 0 to Week 12 (Δ value at Week 12).

To compare two groups in the Week 0 values, an unpaired *t* test (two-sided) was performed, and a *p* value <0.05 was considered to be statistically significant. An intergroup comparison by two-factor repeated measures ANOVA was performed using the actual values from Week 0 through Week 12. Time effects, treatment effects, and interactions of treatment by time were considered to be significant if the *p* value was <0.05. In the case where a treatment-by-time interaction was significant, an unpaired *t* test (two-sided) was performed to compare the Δ values at Week 12 between the two groups, and a *p* value < 0.05 was considered to be statistically significant. When there was a possible confounding factor, Pearson's correlation coefficient was used to examine the association between each parameter. If there was a significant correlation in each group, the effect of adjusting for the covariant was assessed by analyses of covariance.

Two-factor repeated-measures ANOVA, the paired *t* test, and the unpaired *t* test were performed using Stat View for

Table 5. Changes in biochemical parameters after drinking either a GTE beverage high in catechins or a control beverage for 12 weeks (catechin group, $n = 123$; control group, $n = 117$)

	Catechin/ control	Week 0	Week 4	Week 8	Week 12	Δ Value at Week 12*
Serum triacylglycerol (mM)†	Catechin	1.94 (1.03)	1.97 (1.11)	1.82 (0.99)	1.99 (1.21)	0.05 (1.04)
	Control	1.82 (1.07)	1.83 (1.01)	1.72 (1.05)	1.68 (0.89)	−0.13 (0.93)
Serum total cholesterol (mM)‡§	Catechin	5.58 (0.99)	5.37 (0.92)	5.29 (0.90)	5.38 (0.98)	−0.19 (0.65)
	Control	5.44 (0.94)	5.35 (0.92)	5.34 (1.05)	5.31 (0.97)	−0.13 (0.61)
Serum HDL cholesterol (mM)§	Catechin	1.42 (0.37)	1.38 (0.35)	1.36 (0.35)	1.36 (0.33)	−0.06 (0.18)
	Control	1.39 (0.33)	1.38 (0.35)	1.36 (0.33)	1.36 (0.32)	−0.03 (0.17)
Serum LDL cholesterol (mM)‡¶	Catechin	3.41 (0.86)	3.31 (0.87)	3.24 (0.83)	3.31 (0.89)	−0.09 (0.49)
	Control	3.34 (0.82)	3.34 (0.85)	3.38 (0.95)	3.38 (0.86)	0.04 (0.52)
Serum free fatty acid (mM)‖	Catechin	0.60 (0.33)	0.56 (0.29)	0.61 (0.33)	0.59 (0.34)	−0.01 (0.37)
	Control	0.58 (0.31)	0.55 (0.29)	0.59 (0.31)	0.58 (0.30)	0.00 (0.34)
Plasma glucose (mM)	Catechin	5.43 (1.37)	5.40 (1.37)	5.42 (1.36)	5.32 (1.20)	−0.10 (1.04)
	Control	5.17 (1.48)	5.33 (1.86)	5.38 (1.40)	5.19 (1.45)	0.02 (1.36)

GTE, green tea extract. HDL, high-density lipoprotein; LDL, low-density lipoprotein. Values are mean (standard deviation).
* The value is the change from Week 0 to Week 12.
† Calculated as triolein.
‡ There was a treatment-by-time interaction effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
§ There was a time effect using 2-factor repeated-measures ANOVA ($p < 0.05$).
¶ There was a significant difference between the groups in the Δ value at Week 12, as determined using an unpaired t test (two-sided, $p < 0.05$).
‖ Calculated as palmitic acid. The initial values were not significantly different between groups.

Windows version 4.58 (SAS Institute, Inc., Cary, NC), and Pearson's correlation coefficient and analyses of covariance were performed using Enterprise Guide 2.05.89 (SAS Institute, Inc.).

Results

Data were analyzed using the per-protocol samples of 240 subjects (catechin group, 51 women and 72 men; control group, 49 women and 68 men). Averages of age and BMI of 240 subjects were 41.7 ± 9.9 years of age, and 26.8 ± 2.0 kg/m^2, respectively. Thirty subjects were excluded from the original 270 subjects enrolled before the release of the double-blind. Four subjects (catechin group, 1; control group, 3) were discontinued because they moved. Ten subjects (catechin group, 3; control group, 7) were withdrawn for the lack of computed tomography images. Five subjects (catechin group, 4; control group, 1) were not visceral fat-type obese, and 11 subjects (catechin group, 4; control group, 7) were suspected to have hepatic dysfunction.

Compliance of test beverage intake in the catechin group and the control group was 99.1% and 98.9%, respectively.

Table 2 shows the daily energy intake, fat intake, and fat energy ratio. No significant difference in any of the initial values between the two groups was found. Fat intake and the fat energy ratio decreased significantly over time ($p < 0.05$). No significant difference was found between the two groups, however, for energy intake, fat intake, or fat energy ratio. Table 2 also shows the daily intake of tea and coffee as well as tannin and caffeine from these beverages. No significant difference in any of the initial values between the two groups was found. Coffee intake, and tannin and caffeine intake from coffee, decreased significantly over time ($p < 0.05$). However, no significant difference was found between the two groups for tea and coffee intake, or tannin and caffeine intake from these beverages. Daily living records indicated that exercise levels were maintained at a constant level during the trial.

Table 3 shows changes in anthropometric parameters. There was no significant difference in any of the initial anthropometric parameters between the two groups. Body weight, BMI, body fat ratio, body fat mass, waist circumference, and hip circumference decreased significantly over time ($p < 0.05$). Lean body mass increased significantly over time ($p < 0.05$). Significant treatment-by-time interactions were found in body weight, BMI, body fat ratio, body fat mass, waist circumference, and hip circumference ($p < 0.05$).

Table 6. Changes in biochemical and hematologic parameters after drinking either a GTE beverage high in catechins or a control beverage for 12 weeks (catechin group, $n = 123$; control group, $n = 117$)

	Catechin/ control	Week 0	Week 4	Week 8	Week 12	Δ Value at Week 12*
Glutamic-oxaloacetic	Catechin	25.0 (9.0)	24.3 (9.5)	24.8 (11.1)	25.6 (12.0)	0.6 (9.9)
transaminase (IU/L)†	Control	24.2 (10.2)	22.5 (8.6)	23.4 (8.6)	23.8 (9.4)	−0.3 (8.0)
Glutamic-pyruvic	Catechin	34.3 (23.9)	32.0 (21.9)	32.6 (24.9)	33.6 (24.2)	−0.7 (14.0)
transaminase (IU/L)†	Control	33.2 (21.0)	30.9 (18.1)	31.2 (21.1)	32.2 (22.7)	−1.0 (16.9)
γ-glutamyl transferase	Catechin	51.9 (80.4)	49.0 (72.8)	51.1 (79.0)	54.1 (82.6)	2.1 (30.4)
(IU/L)	Control	46.2 (54.3)	47.3 (60.6)	47.6 (63.8)	47.3 (65.3)	1.1 (25.8)
Lactate dehydrogenase	Catechin	308.0 (93.7)	301.8 (95.5)	312.8 (102.1)	303.9 (94.5)	−4.1 (53.3)
(IU/L)†	Control	294.4 (94.5)	290.4 (93.6)	296.7 (95.4)	290.6 (92.6)	−3.8 (37.9)
Alkaline phosphatase	Catechin	202.6 (82.3)	204.2 (84.6)	199.2 (79.9)	199.1 (81.9)	−3.5 (38.1)
(IU/L)†	Control	210.8 (94.9)	211.2 (93.6)	203.7 (82.4)	205.1 (89.8)	−5.7 (32.8)
White blood cells (/μL)	Catechin	6691.2 (1928.2)	6319.6 (1798.9)	6491.8 (1633.4)	6328.9 (1734.4)	−362.4 (1560.1)
	Control	6472.8 (1700.3)	6422.8 (1586.1)	6489.4 (1605.8)	6489.5 (1685.6)	16.7 (1332.7)
Red blood cells	Catechin	473.1 (38.9)	471.4 (39.5)	467.1 (39.7)	466.2 (41.3)	−6.9 (19.8)
($\times 10^4$/μL)†	Control	473.6 (42.1)	475.8 (41.1)	468.2 (42.4)	469.9 (39.3)	−3.8 (20.1)
Hemoglobin ($\times 10^4$/μL)†	Catechin	14.4 (1.4)	14.4 (1.4)	14.3 (1.3)	14.3 (1.3)	−0.1 (0.6)
	Control	14.4 (1.5)	14.5 (1.4)	14.4 (1.5)	14.4 (1.4)	0.0 (0.6)
Hematocrit (%)†	Catechin	44.0 (3.9)	43.9 (3.8)	43.9 (3.5)	43.6 (3.6)	−0.4 (1.9)
	Control	44.1 (3.9)	44.5 (3.6)	44.0 (3.7)	44.0 (3.6)	−0.1 (2.2)
Platelet count ($\times 10^4$/μL)†	Catechin	26.8 (6.2)	26.3 (6.5)	25.9 (5.9)	25.5 (5.9)	−1.3 (3.8)
	Control	27.0 (6.1)	26.1 (6.5)	26.1 (5.6)	25.6 (5.6)	−1.5 (2.9)

GTE, green tea extract. Values are mean (standard deviation).

* The value is the change from Week 0 to Week 12. The initial values were not significantly different between groups.

† There was a time effect using 2-factor repeated-measures ANOVA ($p < 0.05$).

There was no treatment effect for any parameters, but the magnitude of the decrease at Week 12 in body weight, BMI, body fat ratio, body fat mass, waist circumference, and hip circumference was greater in the catechin group than in the control group ($p < 0.05$).

Table 3 also shows changes in abdominal fat areas. No significant difference in any of the initial abdominal fat areas was found between the two groups. TFA and VFA decreased significantly over time ($p < 0.05$). There were significant treatment-by-time interactions in TFA, VFA, and SFA ($p < 0.05$). There was no treatment effect in abdominal fat areas. However, the magnitude of the decrease in the TFA, VFA, and SFA was greater in the catechin group than in the control group ($p < 0.05$).

Table 4 shows changes in circulatory parameters. No significant difference in the actual values or Δ values at Week 12 for SBP or DBP was found in either group. The pulse rate increased significantly over time ($p < 0.05$). No treatment effect or treatment-by-time interaction was found, however, in pulse rate values. The hypotensive effect of catechins was investigated using a stratified analysis of blood pressure based on standard diagnostic values according to the guidelines established by the Japanese Society of Hypertension (10). In subjects with an initial SBP below 130 mm Hg (normal level), SBP increased significantly over time ($p < 0.05$). There was no treatment effect, or treatment-by-time interaction in SBP between the two groups. In contrast, in subjects whose initial SBP was 130 mm Hg or higher, a significant treatment-by-time interaction in the actual SBP values was found ($p < 0.05$). The SBP in these subjects did not show a treatment effect. However, the magnitude of the decrease in SBP was greater in the catechin group than in the control group ($p < 0.05$). No treatment effect or treatment-by-time interaction in DBP was found between the two groups in the stratified analysis of subjects regardless of their initial DBP. There were significant time effects in these stratified analyses. The DBP increased in subjects with low initial DBP (<85 mm Hg, $p < 0.05$), and decreased in subjects with high initial DBP (≥85 mm Hg, $p < 0.05$).

Table 7. Changes from the initial value at Week 12 in the catechin group by gender

	Women		Men	
	Week 0	Δ Value at Week 12*	Week 0	Δ Value at Week 12*
Body weight (kg)†‡	64.9 (6.3)	−1.7 (1.5)	79.2 (7.0)	−1.7 (1.6)
BMI (kg/m^2)†	26.9 (0.8)	−0.7 (0.6)	26.8 (0.8)	−0.6 (0.5)
Body fat ratio (%)†‡	36.4 (4.8)	−2.3 (3.6)	26.7 (4.0)	−2.6 (3.1)
Body fat mass (kg)†‡	23.8 (4.9)	−2.1 (2.8)	21.3 (4.1)	−2.5 (2.4)
Waist circumference (cm)†‡	84.2 (5.0)	−2.7 (2.5)	89.2 (4.3)	−2.3 (1.9)
Hip circumference (cm)†	97.6 (5.4)	−2.6 (2.2)	98.3 (4.1)	−2.1 (1.8)
Total fat area (cm^2)†‡	362.7 (81.3)	−17.1 (62.2)	297.2 (65.9)	−15.2 (31.7)
Visceral fat area (cm^2)†	104.7 (43.2)	−8.9 (24.0)	112.3 (41.6)	−11.3 (22.9)
Subcutaneous fat area (cm^2)†‡	258.0 (69.2)	−8.2 (56.5)	184.9 (45.5)	−3.9 (17.1)
Systolic blood pressure (mm Hg)				
Initial ≥130 mm Hg§	139.0 (7.1)	−10.4 (12.9)	140.4 (8.5)	−8.0 (11.7)
Serum LDL cholesterol (mM)†	3.57 (0.87)	−0.09 (0.56)	3.30 (0.84)	−0.10 (0.43)

LDL, low-density lipoprotein; SD, standard deviation. There was no significant difference between women and men in the Δ value at Week 12 using unpaired *t* test ($p < 0.05$).
* The value is the change from Week 0 to Week 12.
† Values represent the means (SD) for $n = 51$ in women and $n = 72$ in men.
‡ There was a significant difference between women and men in the Week 0 value, as determined using an unpaired *t* test (two-sided, $p < 0.05$).
§ Values represent the means (SD) for $n = 24$ in women and $n = 32$ in men.

The changes in biochemical parameters are shown in Tables 5 and 6. No significant difference in the initial values of the biochemical parameters was found between the two groups. No significant difference was found in serum triacylglycerol, HDL-cho, free fatty acid, or Glc. In contrast, significant treatment-by-time interactions were found in T-cho and LDL-cho. The Δ values at Week 12 of T-cho did not differ between the two groups, but the magnitude of the decrease in LDL-cho was greater in the catechin group than in the control group ($p < 0.05$). There was no significant difference between the two groups in GOT, GPT, γ-GTP, lactate dehydrogenase, alkaline phosphatase, white blood cells, red blood cells, hemoglobin, hematocrit, or platelet count (Table 6). No adverse effect caused by the GTE high in catechins was reported.

The initial values and Δ values at Week 12 in catechin group are shown by gender in Table 7 for the parameters that showed significant intergroup differences in Δ values at Week 12. These parameters were body weight, BMI, body fat ratio, body fat mass, waist circumference, hip circumference, TFA, VFA, SFA, SBP (initial SBP ≥130 mm Hg), and LDL-cho. Although there were significant differences between women and men in the Week 0 values for body weight, body fat ratio, body fat mass, waist circumference, TFA, and SFA, there was no significant difference between women and men in Δ values at Week 12 for any of the parameters.

Since body fat accumulation is a possible confounding factor for cardiovascular risk parameters, the relationship between the changes in cardiovascular risk factors and those in body fat parameters were examined. The correlations between Δ values at Week 12 of SBP, T-cho, HDL-cho, LDL-cho, and Glc, and the Δ values at Week 12 of body weight, body fat ratio, VFA, and SFA, were analyzed by Pearson's correlation coefficient. There was no significant correlation between body fat parameters and cardiovascular risk factors in both groups on a simultaneous correlation analysis (Table 8).

Discussion

The effects of a GTE high in catechins on body fat and cardiovascular risk factors were investigated in an intervention trial without changing the usual lifestyle of the subjects.

The dietary fat intake and fat energy ratio decreased from the initial level in both groups. These decreases might be caused by the seasonal change of the meal (spring to summer), but the usual dietary energy intake and exercise habits

Table 8. Correlation coefficients between cardiovascular risk parameters and body fat parameters by group

Cardiovascular risk parameter	Catechin/ control	Body fat parameter							
		Body weight		Body fat ratio		Visceral fat area		Subcutaneous fat area	
		r	*p*	r	*p*	r	*p*	r	*p*
Systolic blood pressure (mm Hg)*	Catechin	0.187	0.1678	0.105	0.4402	0.014	0.9169	0.139	0.3080
Initial ≥130 mm Hg	Control	0.011	0.9338	0.145	0.2662	0.074	0.5698	0.047	0.7207
Serum total cholesterol (mM)†	Catechin	0.189	0.0359	0.068	0.4517	0.149	0.6251	0.103	0.2589
	Control	0.125	0.1794	0.068	0.4648	−0.024	0.1095	0.110	0.2385
Serum HDL cholesterol (mM)†	Catechin	0.001	0.9884	−0.145	0.1103	−0.115	0.2070	−0.040	0.6576
	Control	−0.039	0.6777	−0.007	0.9362	0.075	0.4217	−0.008	0.9282
Serum LDL cholesterol (mM)†	Catechin	0.092	0.3109	0.095	0.2964	−0.024	0.7919	0.061	0.5049
	Control	0.101	0.2783	0.180	0.0519	−0.008	0.9329	0.056	0.5476
Plasma glucose (mM)†	Catechin	0.011	0.9050	−0.021	0.8137	−0.042	0.6427	−0.038	0.6771
	Control	0.107	0.2489	0.013	0.8908	0.060	0.5176	0.028	0.7628

HDL, high-density lipoprotein; LDL, low-density lipoprotein. Change at Week 12 from the initial was used to calculate Pearson's correlation coefficient. There was no significant correlation in both groups.
* Number of catechin group was 56, and that of control group was 61.
† Number of catechin group was 123, and that of control group was 117.

were maintained throughout the trial. Because daily energy and fat intake for 30- to 49-year-old Japanese are reported to be 8.2 ± 2.4 MJ and 57.1 ± 24.5 g by the National Nutrition Survey in Japan (11), the daily energy and fat intake in the present trial are within these ranges in both groups. Tea and coffee intake decreased in both groups. This might be caused by the loading of the test beverage. Whereas the daily tea intake is 310.3 g/d, and the daily coffee or cocoa intake is 64.8 g/d for Japanese (11), the tea and coffee intake of the subjects in the present trial were about one third and 2 times, respectively, the average for typical Japanese. On the other hand, the catechins and caffeine intake of Japanese subjects were estimated to be ~155 mg/d and 88 mg/d, respectively, based on published data (9,11). Therefore, during the treatment period, the intake of catechins and caffeine, including those in the test beverage, compared with the average for typical Japanese were 1.0 and 1.8 times in the control group, and 4.1 and 1.7 times in the catechin group, respectively. Under the above conditions, the ingestion of a beverage of GTE high in catechins for 12 weeks led to significant decreases in body weight, BMI, body fat ratio, body fat mass, waist circumference, hip circumference, TFA, VFA, and SFA. The results of the present trial further confirmed the results of previous studies on body fat in humans (4,5) by expanding the population of subjects in number and gender. Decrease of LDL-cho was also observed in the present trial, and this result further confirmed the result of previous study (12). The reduction of SBP in the subjects with mild hypertension by GTE high in catechins was observed for the first time in the human study. No significant difference was found between women and men in these effects.

A cluster of conditions, such as obesity, hypercholesterolemia, and hypertension, can lead to cardiovascular disease even if they are mild in each case and is known as the metabolic syndrome (13,14). Visceral fat accumulation-type obesity and insulin resistance are regarded as the primary determinant of the metabolic syndrome (15–17). The ingestion of a GTE high in catechins decreased waist circumference and SBP, which are two of the parameters of the metabolic syndrome established by the National Cholesterol Education Program for Americans (18) or the Japanese Committee for the Diagnostic Criteria of Metabolic Syndrome (19). VFA and LDL-cho were also reduced. These findings suggest that the consumption of a GTE high in catechins may reduce of the risk of the metabolic syndrome.

It is possible that the mechanism by which catechins reduce body fat may be related to the increase of energy expenditure. Dulloo et al. assumed that increase of oxygen consumption and decrease of the respiratory quotient (3) were due to sympathetic nerve-induced thermogenesis caused by the inhibition of catechol O-methyltransferase activity (20). Harada et al. proposed that enhanced dietary fat oxidation and increased dietary-induced thermogenesis (21) were due to increased β-oxidation in the liver (22). In addition, the decrease in blood pressure and cholesterol may be the result of body fat reduction. On the other hand, Ajay et al. proposed that flavonoids containing EGCG exert a vasorelaxant action causing the release of nitric oxide and prostaglandin (23). Abe et al. reported that EGCG, GCG, and ECG are potent and selective inhibitors of rat squalene epoxidase, the rate-limiting enzyme in cholesterol biosynthesis (24). In the present trial, the reduction in body fat was not significantly correlated with the decrease in cardiovascular risk factors. The relationship between the initial body fat parameters and changes at Week 12 for cardiovascular risk factors was then analyzed. With the exception of a few cases, such as initial body fat ratio and Δ value at Week 12 for pulse rate, there was no apparent correlation between the decrease in cardiovascular risk factors and the initial values for body fat parameters (data not shown). Collectively, these results indicate that the actions of catechins on body fat, blood pressure, and serum cholesterol might be controlled by a separate mechanism. Further study will be necessary to elucidate the mechanism of action of catechins, including their absorption, metabolism, and excretion.

In summary, this trial clarified that the continuous ingestion of catechins, especially in high amounts, reduces body fat, cholesterol levels, and blood pressure in women and men without the need for any lifestyle changes. The ingestion of a GTE high in catechins might prevent obesity and decrease the risk of cardiovascular disease.

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