Effects of Catechin Enriched Green Tea on Body Composition

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Obesity is a major health problem in the developed and developing world. Many "functional" foods and ingredients are advocated for their effects on body composition but few have consistent scientific support for their efficacy. However, an increasing amount of mechanistic and clinical evidence is building for green tea (GT). This experiment was therefore undertaken to study the effects of a high-catechin GT on body composition in a moderately overweight Chinese population. In a randomized placebo-controlled trial, 182 moderately overweight Chinese subjects, consumed either two servings of a control drink (C; 30 mg catechins, 10 mg caffeine/day), one serving of the control drink and one serving of an extra high-catechin GT1 (458 mg catechins, 104 mg caffeine/day), two servings of a high-catechin GT2 (468 mg catechins, 126 mg caffeine/day) or two servings of the extra high-catechin GT3 (886 mg catechins, 198 mg caffeine/day) for 90 days. Data were collected at 0, 30, 60, and 90 days. We observed a decrease in estimated intra-abdominal fat (IAF) area of 5.6 cm^2 in the GT3 group. In addition, we found decreases of 1.9 cm in waist circumference and 1.2 kg body weight in the GT3 group vs. C ($P < 0.05$). We also observed reductions in total body fat (GT2, 0.7 kg, $P < 0.05$) and body fat % (GT1, 0.6%, $P < 0.05$). We conclude that consumption of two servings of an extra high-catechin GT leads to improvements in body composition and reduces abdominal fatness in moderately overweight Chinese subjects.

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INTRODUCTION

Tea is the most widely consumed beverage in the world, second only to water. The three kinds of true tea—green, black, and oolong—are all derived from the *Camellia sinensis* plant. At harvest tea leaves contain high levels of catechins, a particular class of polyphenols (1). After harvest catechins may be rapidly converted by enzymatic oxidation to a complex mixture of other derivatives, thearubigins and theaflavins, responsible for the characteristic color of oolong and black tea. Green tea (GT), however, is produced by heat-treating leaves soon after harvest, thereby preserving the catechins from oxidation.

The amount of catechins in a cup of GT is highly variable, depending on the precise type of tea, the ratio of dry tea to water and on the time that the leaves are infused before consumption. An average serving of 250 ml of GT contains between 50 and 100 mg of catechins. In addition, GT contains a variable amount (typically around 30 mg/serving) of caffeine (2).

Studies in humans and experimental animals provide epidemiological, mechanistic, and experimental evidence linking regular tea consumption to several health benefits (1–3). Most research has focused on the function of the antioxidant components found in tea and the potential of these to reduce the risk of cardiovascular disease and cancer (1,4). In addition, a number of reports have been published showing that regular consumption of GT, or catechins extracted from GT (with or without added caffeine), may influence energy metabolism, body weight and body fat content (for reviews see refs. 1,2,5,6). Furthermore, there is some evidence suggesting that consumption of GT, or catechins extracted from green or oolong tea may have a particular influence on subcutaneous abdominal fat and on fat depots surrounding the abdominal organs; also known as visceral fat (7–9).

In this large, double-blind placebo-controlled trial we investigated the effects of consuming GT with different amounts of catechins on measures of body weight, total body fat mass and the distribution of fat between abdominal and other depots. The study was carried out in an urban setting in a moderately overweight, free-living, Chinese population.

METHODS AND PROCEDURES

Subjects

From an initial respondent pool of 435 subjects living in Shanghai, 205 moderately overweight subjects (according to the World Health Organization guidelines for this population (10)) met the screening criteria below and entered the trial.

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The criteria for inclusion in the trial were: (i) age between 18 and 55 years; (ii) BMI between 24 and 35 kg/m^2; (iii) body fat >25% for males and >30% for females; (iv) waist circumference >85 cm for males and >80 cm females; (v) normal liver function, as assessed by plasma enzyme profile and total bilirubin levels; (vi) low caffeine consumption (<200 mg/day); (vii) low tea consumption (<2 tea bags/day or <4 g loose tea/day); (viii) nonsmoking; (ix) zero or moderate (i.e., <14/week for women and <21/week for men) alcohol consumption.

The criteria for exclusion from the trial were: (i) use of any medication, apart from over the counter and oral contraceptives; (ii) suffering from any medical or psychiatric condition; (iii) actively following a weight loss regimen or a medically prescribed dietary regime; (iv) losing or gaining >2 kg body weight in the 3 months before the start of the trial.

The study protocols and informed consent documents were approved by the Unilever R&D ethics committee in June 2006, which was formed by a number of external and independent experts from universities and hospitals in Shanghai, and a consumer representative. This study was carried out according to the guidelines of Good Clinical Practice and in accordance with the declaration of Helsinki.

The response variable of main interest was body weight. Based on an estimated within subject variance of body weight of about 1.5 kg; we calculated that 205 subjects should be sufficient to detect a difference of at least 0.716 kg with a power of 80%, $\alpha = 0.05$ (one sided).

Study design

This randomized, placebo-controlled study used a between-subject design, and was comprised of 3 phases: phase 1: recruitment and screening of volunteers; phase 2: 2 week run-in period during which subjects consumed one serving of control beverage per day at the study site to test adherence to GT drinking and protocol compliance; phase 3: 90 days of intervention period during which the subjects consumed one of four test treatments described in the section on test drinks.

Subjects were randomly allocated to one of four groups. Randomization of subjects into experimental groups was based on stratification by BMI, waist circumference/height, and gender. Subjects attended the study centre two times every day, at the same time of morning and afternoon, to consume their designated test beverages containing defined amounts of catechins and caffeine. An interval of at least 4 h was required between the two visits, and the subjects were required to take a meal (breakfast with the first supplement, and lunch òr dinner with the second), before they took their beverage. They were instructed not to consume any other beverages containing catechins, or caffeine during the intervention period and they were asked to use the same mode of transportation to report to the research facility throughout the intervention.

On days 0, 30, 60, and 90 of the intervention period, subjects completed a schedule of anthropometric measures, blood draws, and questionnaires, as described below.

Test drinks

The beverages were prepared by adding 250 ml of hot water to the test teas contained in a tea bag, following a standard infusion protocol. Test teas were: control drink C: prepared from GT leaf (1.5 g) from which the catechins had been extracted. To ensure that subjects would not know they were consuming a control treatment, a small amount of unextracted green leaf (0.5 g) and tea powder perfume were added. High-catechin drink H: prepared from green leaf tea (2.5 g); extra high-catechin drink EH: prepared from green leaf tea (1.25 g), enriched with catechin powder (0.3 g) and 0.45 g GT powder.

The caffeine and catechin concentrations of our test drinks were analyzed using a Luna 5 µ phenyl-Hexyl high performance liquid chromatography Column (Torrance, CA) coupled with a Waters 2695 pump at a wave length of 278 nm. Data were collected using a Masslynx 4.1 collection system (Waters, Milford, MA). Total catechin was determined by the addition of EGC, GC, EC, C, EGCG, GCG, ECG, and CG. CG was below detection limit in all our samples. EGC, C, EGCG, EC, ECG, and caffeine were quantified by a high performance liquid chromatography standard curve drawn from caffeine (at 4, 10, 20, 40, 100, 200, 300, 400 ppm) multiplied by relative response factors. GC and GCG were quantified by their standard solutions at 1, 2.5, 5, 10, 25, 50, 75, and 100 ppm.

An average 250 ml cup of GT from commercial products in the Chinese market when prepared according to the instructions given on their packaging contains on average 83 mg of catechins and 42 mg caffeine (11). Therefore, the amounts consumed by the subjects in this study were equivalent to 6–10 cups of a regular Chinese type of GT per day, depending on the treatment group.

For further details about the administration of the test drinks, see Table 1.

Anthropometric measures

Anthropometric measurements were performed in the morning after a 12-h fast and after voiding. These included waist and hip circumference, sagittal diameter, body weight, whole body fat mass, and height. In addition, body fat % was measured at 0, 60, and 90 days with a QDR4500W Dexa (fan beam) (Hologic, Waltham, MA). Intra-abdominal fat (IAF) was estimated from segmental DXA analyses of trunk fat and sagittal diameter (using a Holtain-Kahn abdominal calliper; Holtain, Dyfed, Wales) by the equation of Treuth *et al.* (12):

$$\begin{aligned}\mathrm{IAF}\left(\mathrm{cm}^2\right) = &-208.2 + 4.62\ \text{sagittal diameter (cm)} \\ &+ 0.75\ \text{age (years)} + 1.73\ \text{waist circumference (cm)} \\ &+ 0.78\ \text{DXA trunk fat (\%)}.\end{aligned}$$

Health, lifestyle, product liking, and dietary questionnaires

At the study visits at $t = 0$ and 90 days, the subjects filled out general questionnaires about dietary and lifestyle habits, self perceived health status and product liking. English translations of these questionnaires are available from the authors upon request. Although food intake was not a key variable in this study, a 3-day food intake questionnaire was also used to assess general food intake patterns. Although this method will provide us with an estimate of the food intake of our subjects, it should be noted that any type of dietary intake assessment is prone to systemic bias, most usually in the direction of underreporting (13).

Blood parameters

Blood samples were taken at intervention days 0, 60, and 90 for the analysis of lipids (triglycerides, total cholesterol, low-density lipoprotein cholesterol and high-density lipoprotein cholesterol), and blood glucose, and at days 0 and 90 for the determination of alanine aminotransferase, aspartate aminotransferase; alkaline phosphatase; γ-glutamyltransferase; lactate dehydrogenase to assess liver function. Immediately, after the blood sample was obtained, plasma was separated by centrifugation and stored appropriately for the further analysis.

Table 1 Test drink composition

Intervention group	Test drink 1	Test drink 2	Total daily catechin intake	Total daily caffeine intake
C	C	C	30 mg	10 mg
GT1	EH	C	458 mg	104 mg
GT2	H	H	468 mg	126 mg
GT3	EH	EH	886 mg	198 mg

C = control drink containing 15 mg catechins and 5 mg caffeine per serving. EH = extra high-catechin green tea beverage containing 443 mg catechins and 99 mg caffeine per serving. H = high-catechin green tea beverage containing 234 mg catechins and 63 mg caffeine per serving.
GT, green tea.

Glucose, triglycerides, total cholesterol, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol and the various liver function parameters were all analyzed with an enzymatic colorimetric test on a Hitachi 7170A automatic analyser (Hitachi Corporation, Tokyo, Japan). Glucose, triglycerides, total cholesterol, low-density lipoprotein cholesterol, and the liver function parameters alanine aminotransferase, alkaline phosphatase, and γ-glutamyltransferase were analyzed with reagents from KBH (Shanghai, China). Liver function parameters Aspartate aminotransferase and lactate dehydrogenase were analyzed with reagents from AusBio Laboratories (Yanthai, China). High-density lipoprotein cholesterol was analyzed with reagent from Roche Diagnostics (Basel, Switzerland).

Statistical analysis

Statistical analyses were performed using SAS software (version 9.1; SAS Institute, Cary, NC). An ANOVA-based linear model was used to analyse the results. The model accounted for treatment group, subjects and time points as factors.

A repeated measures variance structure was used to accommodate repeated testing of the same subjects and baseline values were included as covariates. All statistical tests were performed 2-sided with a significance level of 5%.

RESULTS

Out of the 205 subjects randomized to treatments, 13 dropped out for various personal reasons unrelated to the trial, and 192 completed the study. A further 10 subjects were excluded during blind review because of poor compliance (i.e., missing intermediary study visits ($n = 3$), not adhering to the fasting regime the night before study visits ($n = 5$), change in diet or lifestyle habits ($n = 2$)). Analyses were therefore carried out and reported on the remaining 182 subjects (133 women, 49 men).

Baseline demographic and anthropometric characteristics of all intervention groups were similar (Tables 2 and 3). Relative to the control (group C), body weight and waist circumference in group GT3 were significantly reduced at the end of the 90 day intervention. We observed significant differences as well with respect to the DXA body composition measurements at 90 days (Table 4). Relative to group C, there were significant decreases in calculated IAF and a small but statistically significant decrease in total lean mass in group GT3 ($P < 0.05$). Although the data might appear suggestive of a possible time × treatment interaction for the effect of GT on IAF, this did not approach statistical significance ($P = 0.17$). Significant decreases in total fat mass and % fat relative to the change in control were observed in groups GT2 and GT1, respectively but total fat mass and % fat was not changed in GT3.

The average reported energy intake in all groups and time points ranged from 7.9–8.4 MJ/day; reported energy and macronutrient intakes did not differ between groups nor change during the course of intervention (**Supplementary Table S1** online).

The plasma high-density lipoprotein cholesterol and low-density lipoprotein cholesterol levels, plasma triglycerides, and glucose measures, and the responses to questionnaires did not differ between the treatments (**Supplementary Table S2** online). The baseline covariate was statistically significant for all of these plasma measures, indicating a general regression toward the mean for all groups, unrelated to treatment. Liver function tests did not show any treatment-related differences

Table 2 Subject characteristics at baseline

Measurement	C ($n = 43$)	GT1 ($n = 47$)	GT2 ($n = 49$)	GT3 ($n = 43$)
Age (years)	37.0 (8.9)	36.6 (9.1)	37.3 (10.1)	37.5 (9.1)
Weight (kg)	69.7 (8.9)	71.4 (9.8)	71.5 (11.8)	71.1 (11.9)
Height (m)	1.61 (0.06)	1.62 (0.08)	1.62 (0.08)	1.62 (0.09)
BMI (kg/m^2)	26.8 (2.0)	27.1 (2.2)	27.2 (2.5)	26.8 (2.2)

None of these differences were statistically significant between groups. All values are mean (s.d.).
GT, green tea.

Table 3 Changes in anthropometric values after consumption of green tea beverages with different compositions or a control beverage

	Treatment[a]	0 days	30 days	60 days	90 days	Mean % change[b]
Body weight (kg)	C	69.7 (8.9)	70.0 (9.0)	69.7 (9.0)	69.8 (9.1)	+0.1%
	GT1	71.4 (9.8)	71.2 (9.9)	71.0 (10.1)	70.7 (10.1)	–1.0%
	GT2	71.5 (11.8)	71.2 (11.8)	71.0 (11.8)	70.7 (11.7)	–1.0%
	GT3	71.1 (11.9)	70.6 (11.7)	70.3 (12.0)	69.9 (12.1)*	–1.7%
Waist circumference (cm)	C	94.5 (6.0)	94.4 (5.7)	94.2 (0.9)	94.3 (5.8)	–0.2%
	GT1	96.1 (5.8)	95.7 (6.0)	95.2 (0.9)	95.0 (6.2)	–1.1%
	GT2	95.9 (7.0)	95.5 (6.7)	95.1 (1.0)	94.6 (7.0)	–1.3%
	GT3	95.5 (6.9)	94.4 (6.9)	94.0 (1.1)	93.6 (7.0)*	–2.0%
Hip circumference (cm)	C	99.2 (4.4)	99.0 (4.4)	99.0 (4.6)	98.9 (4.6)	–0.3%
	GT1	99.7 (4.4)	99.3 (4.7)	99.0 (4.6)	98.8 (4.7)	–0.9%
	GT2	99.2 (5.4)	98.7 (5.2)	98.4 (5.3)	98.4 (5.4)	–0.8%
	GT3	99.0 (5.1)	98.8 (5.3)	98.4 (5.4)	98.3 (5.7)	–0.8%

All values are mean (s.d.).
GT, green tea.
[a]Subject numbers for each group were: C: $n = 43$, GT1: $n = 47$, GT2: $n = 49$, GT3: $n = 43$. [b]These changes are relative to baseline and reflect mean change across subjects, not change in means as tabulated.
*Difference between treatment and placebo in terms of change from baseline ($P < 0.05$).

Table 4 Changes in body composition after consumption of green tea beverages with different compositions or a control beverage

Measurement	Treatment[a]	0 days	60 days	90 days	Mean % change[b]
IAF (cm^2)[c]	C	80.4 (3.1)	79.1 (2.9)	79.3 (2.9)	–1.0%
	GT1	85.0 (2.8)	82.6 (3.1)	81.0 (3.0)	–5.0%
	GT2	84.7 (3.1)	82.4 (3.0)	81.1 (3.1)	–4.2%
	GT3	83.6 (3.2)	78.8 (3.3)	78.0 (3.4)*	–7.1%
Total lean mass (kg)	C	46.2 (1.2)	46.6 (1.3)	45.8 (1.1)	0.6%
	GT1	47.6 (1.3)	47.8 (1.4)	47.7 (1.3)	0.2%
	GT2	46.8 (1.2)	47.5 (1.3)	47.5 (1.4)	0.4%
	GT3	47.4 (1.4)	47.0 (1.5)	47.1 (1.5)*	–0.9%
Total fat mass (kg)	C	22.7 (0.5)	22.5 (0.5)	22.4 (0.5)	–2.0%
	GT1	22.8 (0.5)	22.6 (0.6)	22.2 (0.5)	–2.4%
	GT2	23.0 (0.7)	22.6 (0.7)	22.4 (0.6)*	–2.4%
	GT3	22.8 (0.7)	22.5 (0.8)	22.2 (0.7)	–1.0%
Fat %	C	33.2 (4.7)	32.5 (4.7)	33.0 (4.7)	–0.8%
	GT1	32.7 (5.1)	32.4 (5.4)	32.0 (5.1)*	–2.7%
	GT2	33.1 (5.0)	32.4 (5.9)	32.2 (4.9)	–3.1%
	GT3	32.7 (5.3)	32.6 (5.4)	32.2 (5.2)	–2.4%

All values are mean (s.d.).
GT, green tea; IAF, intra-abdominal fat.
[a]Subject numbers for each group were: C: $n = 43$, GT1: $n = 47$, GT2: $n = 49$, GT3: $n = 43$. [b]These changes are relative to baseline and reflect mean change across subjects, not change in means as tabulated. [c]IAF was estimated from segmental DXA analyses using the equation of Treuth *et al.* (12). IAF (cm^2)= –208.2 + 4.62 sagittal diameter (cm) + 0.75 age (years) + 1.73 waist circumference (cm) + 0.78 DXA trunk fat (%).
*Difference between treatment and placebo in terms of change from baseline ($P < 0.05$).

(**Supplementary Table S3** online). The test drinks were generally well tolerated and no adverse events were reported.

DISCUSSION

This investigation shows that regular consumption of a very-high catechin GT over 90 days leads to significant reductions in measures such as body weight, waist circumference and IAF in a population of moderately overweight Chinese males and females. The treatment with the highest daily intake of catechins and caffeine had the most consistent effects on IAF, and the pattern of response to the different tea products and regimens in this study is suggestive of a possible dose–response effect on IAF, although this was not consistent across the other measures. This raises the possibility that a very high-catechin GT could have a disproportionate effect on reducing fat mass in visceral and abdominal adipose depots, fat storage sites which may be particularly associated with metabolic disease risk (14). As has been described previously (see ref. 15 for a review), caloric restriction leading to weight loss will always affect all tissue types, i.e. next to a decrease in fat stores, a certain net decrease in protein degradation leading to a decrease in lean tissue may also be expected.

There is a strong body of evidence for beneficial effects on body composition of consumption of high-catechin GT in particular from trials with Japanese adults (7–9,16–18). These trials were all rather similar in design (i.e., they compared the effects of a placebo to 1–2 daily servings of a GT beverage containing 550–900 mg of catechins, the subjects in these experiments were overweight or obese, and the intervention period was around 12 weeks). The effects of GT supplementation on visceral adipose tissue and abdominal obesity in these trials have been particularly consistent. Significant improvements in body composition parameters have also been observed in some (19,20), though not all (21) studies of other Asian populations. The subjects in those studies were instructed to follow their habitual patterns of food intake and exercise, so effects were measured against the background of habitual levels and variation in energy intake and energy expenditure. These experimental designs and the amounts, frequencies and beverage (or pill) forms of catechins consumed have typically reflected a realistic consumer situation.

There are fewer and less consistent data from studies in western populations. Kovacs *et al.* (22) found no overall effect of a GT-caffeine mixture (270 mg epigallocatechin gallate, 150 mg caffeine) on weight regain in Dutch subjects, following a period of weight loss on a very low energy diet. However, in a separate analysis of the same data, Westerterp-Plantenga *et al.* (23) observed that in subjects with a low habitual caffeine intake, those who received the GT extract continued to lose body weight, waist circumference and body fat, compared with controls. This treatment effect was not apparent amongst high habitual caffeine consumers. In a separate study of Dutch subjects (24) GT extracts did not add to rates of weight loss with meal replacements. The effects of active weight loss may have obscured an additional effect of GT, subjects' caffeine intake also was standardized at 300 mg per day in that study.

It is possible that GT-caffeine mixtures may be more likely to significantly affect energy balance in subjects who consume low amounts of caffeine. The subjects in our study were all selected to have a low habitual caffeine intake, and this may have had a favorable effect on the results.

Recent studies have explored whether the benefits of GT are more apparent in more active individuals. Hill *et al.* (25) observed no added benefit of 300 mg EGCG as part of an activity programme in Australian women. However, Maki *et al.* more recently reported that consumption of 625 mg of GT catechins per day for 12 weeks enhanced the effects of an exercise intervention in overweight and obese North-American adults (26).

There are several potential mechanisms of action for an effect of GT catechins on body composition. First, it has been demonstrated that short-term supplementation with GT (26–28) or catechins alone (29) at rest (27,28) and in combination with light to moderate physical activity (29) can increase fat oxidation. In line with these observations, there is evidence for a chronic stimulating effect of catechin-enriched beverages on particular aspects of energy metabolism from Asian populations. For example, Harada *et al.* (30) and Ota *et al.* (31) report both acute and chronic effects on energy metabolism during exercise and postprandially.

Caffeine has been shown to inhibit the intracellular activity of phosphodiesterase, which decreases the breakdown of cyclic adenosine monophosphate (1) and could also act on the sympathetic nervous system through an antagonism of the negative modulatory effect of adenosine on noradrenalin release (32), thus causing increased sympathetic nervous system activity. Interestingly, physical activity also causes an increase in sympathetic nervous system activity, stimulating fat and carbohydrate oxidation to meet altered energy requirements (33).

Catechins in GT could act synergistically with either or both of these mechanisms because they may inhibit the activity of catechol-o-methyltransferase. This enzyme catalyzes the breakdown of noradrenalin in neural synapses. Inhibition of catechol-o-methyltransferase could increase the wash-out time of noradrenalin, causing a more prolonged stimulation of the sympathetic nervous system, thus increasing energy expenditure (34). In support of this hypothesis, GT intervention studies in which a small to moderate amount of physical activity was incorporated into the design, have consistently shown a decrease in visceral fat and/or other measures of body composition (26,35,36). Furthermore, GT supplementation has also been shown to increase mRNA expression of enzymes related to β-oxidation in muscle and liver tissue in animal studies (37–40).

Another mechanism potentially contributing to the beneficial effects of GT on body composition is a decreased nutrient absorption. Although most evidence comes from animal studies (41–43), there is also some evidence of small but consistent effects of oolong tea, which is also rich in catechins, on fat absorption in humans (44).

Overall, the literature suggests several plausible mechanisms by which GT may influence energy balance and body composition. These may each be of a relatively small absolute magnitude in the short-term, but nevertheless relevant. The additional 0.6 kg loss of fat mass observed in the tea treatment groups relative to control over the course of this study would reflect a negative energy balance of ~0.25 MJ/day over 90 days. Given that we have observed previously that GT does not affect appetite-related parameters and/or food intake (E.M.R. Kovacs and J.A. Rycroft, unpublished data), and also found no evidence for such effects on energy intake in the present study, this negative energy balance in most likely attributable to increased energy expenditure or decreased nutrient absorption. Acute increases in 24-h energy expenditure of ~0.3–0.4 MJ have previously been observed in humans (27,28) and increases in fecal fat excretion of around 3 g or ~0.12 MJ have been shown as well (44) so effects could be explained by these mechanisms. This level of effect would be very difficult to measure in any acute experiment, but the sustained, cumulative effect could be significant and meaningful.

One of the strengths of the present study is that we are sure to have 100% compliance because the test products were consumed at the research facility. Furthermore, we chose to study moderately overweight subjects, which is an important target group for delivering improved metabolic health. The study was sufficiently powered to detect significant differences between the treatment groups in the relevant time frame. Finally, it is a strength of this study that we instructed our subjects to use the same mode of transportation to report to the research facility throughout the intervention.

A potential weakness is that we did not have full control of the dietary intake and physical activity of the subjects during the intervention. It is possible that the GT interventions caused a selective change in eating patterns, energy intake or activity patterns. Questionnaire measures of dietary intake did not change throughout the study, but this was a relatively crude instrument. Moreover, in contrast to other proposed mechanisms noted here, there is no previous clinical or mechanistic support that would lead us to hypothesize behavioral effects such as effects on dietary intake or physical activity. Furthermore, this study was also not intended to study these behavioral effects as potential mechanisms, but to evaluate the effects of GT against the background of normal daily patterns.

It should also be noted that the Treuth formula used to calculate IAF was validated in a western female population. However, to our knowledge, there is no similar equation available for use in overweight Asian populations. Any uncertainty that may arise as a consequence of using the Treuth formula, should be similar across the entire study population, and would not be expected to be biased in favor of one specific treatment.

Furthermore, it would have been very informative to be able to correlate increases in plasma catechins and changes in fat mass (although there is still some question over whether catechins themselves or metabolites—not fully known—may be the primary mediators or best biomarkers of biofunctionality), but measurements of plasma catechin levels were not performed in this experiment.

Moreover, we obtained blood samples at ~18 hours after consumption of the last treatment in each condition. According to earlier studies (45,46), the plasma peak of catechins is reached during the first hours postingestion, so the timing of our blood sampling would not have allowed us to draw correlations between the bioavailability of the catechins and the main outcome measures.

Finally, this study and most others have focused on Asian subjects, so it may be argued that further research is needed to substantiate and generalize these results to western populations. Results could vary as a function of population differences in genetic background and heterogeneity, body composition, and dietary habits.

In conclusion, the results from the present investigation build upon existing evidence for the beneficial effects of GT on body composition in overweight Asian populations. These consistently suggest that daily consumption of 500–900 mg of GT catechins with low-to-moderate amounts of caffeine (i.e., <200 mg) for at least 90 days can exert a positive effect on body composition, and abdominal fat mass in particular, in Asian populations.

SUPPLEMENTARY MATERIAL

Supplementary material is linked to the online version of the paper at http://www.us.nature.com/oby

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H.W. was the principal investigator, supervised the measurements and contributed to the writing of the manuscript; Y.W., Y.D., and X.Y. were all involved with the practical work of the trial. H.G. supervised the clinical measurements; N.B. and J.R. contributed to data interpretation and writing of the manuscript; E.K. and D.M. contributed to the writing of the manuscript and the study protocol.

DISCLOSURE

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