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ORIGINAL CONTRIBUTION

# Tea consumption is inversely associated with weight status and other markers for metabolic syndrome in US adults

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**Abstract**

*Purpose* Tea (*Camellia sinensis*) is a widely consumed beverage, and laboratory and some intervention studies have indicated the potential health benefits of hot tea. The present study examines the association between tea consumption (evaluating hot and iced tea independently) and markers for metabolic syndrome adults in a sample of 6,472 who participated in the 2003–2006 National Health and Nutrition Examination surveys.

*Methods* Tea consumption was evaluated using food frequency questionnaires and 24-h dietary recalls. Seventy percent of the sample reported any consumption of iced tea and 16 % were daily consumers, whereas approximately 56 % of this sample reported hot tea consumption and 9 % were daily consumers.

*Results* Hot tea consumption was inversely associated with obesity: tea consumers had lower mean waist circumference and lower BMI (25 vs. 28 kg/m$^2$ in men; 26 vs. 29 kg/m$^2$ in women; both $P < 0.01$) than non-consumers after controlling for age, physical activity, total energy intake, and other confounders. For iced tea consumption, the association was reversed: increased iced tea consumption was associated with higher BMI, greater waist circumference, and greater subcutaneous skinfold thickness after controlling for age, physical activity, energy intake, sugar intake, and other confounders. Hot tea consumption was associated with beneficial biomarkers of cardiovascular disease risk and inflammation (increased high-density lipoprotein-associated cholesterol and decreased C-reactive protein in both sexes, and reduced triglycerides in women), whereas the association with iced tea consumption was again reversed.

*Conclusions* These cross-sectional results support growing laboratory data, which demonstrate the negative association of hot tea intake with markers of MetS.

**Keywords** NHANES · Tea · Obesity · Waist circumference · BMI · Metabolic syndrome

**Abbreviations**

| | |
|---|---|
| BMI | Body mass index |
| EGCG | (−)-Epigallocatechin-3-gallate |
| FFQ | Food frequency questionnaire |
| NHANES | National Health and Nutrition Examination Survey |
| PIR | Poverty/income ratio |
| WC | Waist circumference |

## Introduction

Tea is the most widely consumed beverage in the world aside from water [1]. Derived from steeping the leaves of *Camellia sinensis* in water, tea contains high concentrations of polyphenolic compounds [2]. The three major types of tea—black, oolong, and green—differ in terms of processing, chemical composition, and consumption patterns. Green tea is consumed primarily in Japan, China, and a small subset of Middle Eastern and North African countries [1]. During the processing of green tea, fresh

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leaves are pan-fried to inactive endogenous polyphenol oxidase that preserves the characteristic monomeric flavan-3-ols known as catechins. (−)-Epigallocatechin-3-gallate (EGCG) is the most abundant and widely studied green tea catechin [3]. By contrast, during the processing of black tea, fresh leaves are crushed and allowed to undergo oxidation resulting in the formation of polyphenolic oligomers and polymers known as theaflavins and thearubigins. Black tea is commonly consumed primarily in Europe, India, and the United States. Oolong tea is a product that undergoes an intermediate level of oxidation and is consumed most widely in China. In addition to their respective polyphenols, these three types of tea contain comparable amounts of caffeine.

Tea and tea polyphenols have been extensively studied for their potential as preventive agents for cancer, heart disease, neurodegenerative disease, and other chronic conditions [4–6]. A growing number of laboratory and human intervention studies have suggested that tea and tea polyphenols may be useful for the prevention of obesity and metabolic syndrome (MetS) [7–14].

A limited number of epidemiological studies have been conducted to determine the association between tea consumption and body weight [15–17]. Wu and colleagues (ref) found that habitual tea consumption (primarily green and oolong) was associated with lower waist/hip ratio in Taiwanese adults; Hughes and colleagues [16] found that black tea consumption was associated with lower BMI in the Netherlands. Most recently, a cross-sectional study between tea consumption and body weight status in US adults was reported by Bouchard and colleagues [17]. The authors found that tea was inversely related to waist circumference; however, the method for evaluating tea intake was relatively weak; the authors used only a single cycle of NHANES, which was not adequately weighted for generalizable analysis. In addition to obesity, a number of epidemiological studies have examined the relationship between tea consumption and various glycemic measures (fasting glucose, fasting insulin, insulin sensitivity) but the results are mixed and are very population-specific [18–20], warranting further investigation.

To our knowledge, no studies have been conducted to determine the association between tea consumption and multiple markers for MetS in US adults. Although the current literature derived from weight-loss trials is useful in assessing the utility of tea supplementation for improving body weight status in individuals actively trying to lose weight, larger data sets are needed to evaluate whether regular tea consumption is associated with lower body weight in persons *regardless* of intentions for weight loss. Further, more studies are needed to assess the potential effects of black tea on MetS, given that it accounts for almost 80 % of worldwide tea production [2].

The objective of this study was to determine the relationship between tea consumption (including black, green, and oolong, both hot and iced) and markers for MetS in a representative sample of 5,948 adults (54 % female) from the 2003–2006 National Health and Nutrition Examination Survey (NHANES) data. Using these NHANES data, the association of tea consumption with multiple markers for MetS including body mass index (BMI), waist circumference (WC), fasting glucose, total cholesterol, HDL-cholesterol, LDL-cholesterol, serum triglycerides, and C-reactive protein was explored.

## Subjects and methods

### The NHANES

The NHANES is a large, cross-sectional survey conducted by National Center for Health Statistics. NHANES is designed to monitor the health and nutritional status of non-institutionalized civilians in the United States; data are collected on a continual basis and released in two-year increments. Complete details regarding the NHANES sampling methodology, data collection, and interview process are available on the NHANES Web site (http://www.cdc.gov/nchs/nhanes.htm). Data from the 2003–2004 and 2005–2006 NHANES survey cycles were combined for this study to maximize power. These cycles were chosen due to the use of both Food Frequency Questionnaire (FFQ) and 24-h recall data as methods of dietary assessment. Specific status codes were used to indicate the quality, reliability, and completeness of the dietary data. One day of dietary recall data was collected by trained interviewers from participants during their visit to the Mobile Examination Unit; a second day of dietary data was collected using an interviewer–administered phone survey. A status code was used in the data set following each recall to indicate the completeness of the data.

### Subjects

For this analysis, all adults 18 years of age or older were initially included ($n = 11{,}183$). Adults who did not have 2 had 2 days of reliable 24-h recall data in addition to FFQ data ($n = 3{,}505$) were excluded, as well as pregnant and lactating women ($n = 364$) were excluded from this analysis since WC and weight status were primary outcome measures. Participants with abnormal or implausible dietary recall (>7,500 or <300 kcal/day; $n = 149$), or who reported currently following a weight-loss diet ($n = 557$) were dropped from the analysis in order to maximize accuracy. Participants with missing outcome measures ($n = 140$, i.e., BMI, WC) were also eliminated, resulting in a final analytical sample of 6,472 (due to overlap of missing components) adults (53 % female) for analysis regarding tea consumption and anthropometric measures. Of these adults, a small subset also underwent additional procedures to collect fasting (3,118) blood samples. Age at the time of examination, education level, smoking status (current, former, and non-smoker), physical activity (measured in MET units), race, and socioeconomic status were all provided in the NHANES data set. Socioeconomic status was quantified as a continuous variable using poverty/income ratio (PIR) or the ratio of family income to family-size-specific poverty threshold. Participants were coded into one of four categories of tea consumption for both hot and iced tea: non-consumers (rarely or never drink tea), infrequent consumers (1 c/week or fewer), weekly consumers (2–6 c/week), daily consumers (1 c/day), or multiple cups/day. Participants were also queried about the amount of herbal or decaffeinated tea that was consumed.

### Markers for metabolic syndrome

Weight status was assessed using BMI (kg/m$^2$). In both cycles of NHANES, height and weight were measured by trained examiners using standardized protocols and calibrated equipment. Weight status in adults was defined using CDC cut points (http://www.cdc.gov/obesity/defining.html). Adults were classified as lean (BMI $\leq$24.9), overweight (BMI of 25.0–29.9), or obese (BMI $\geq$30). Body fatness was evaluated using two measures: WC and skinfold thickness. Complete details of anthropometric measurements can be found on the NHANES Web site (www.cdc.gov/nchs/nhanes). Briefly, triceps and subscapular skinfold thickness were assessed on using calibrated skinfold calipers on the right side of the body; waist circumference was measured by using a soft tape measure placed horizontally just above the iliac crest.

Blood samples were collected on a smaller subset of the population to asses other markers for MetS. As with the anthropometric data, full details regarding specimen handling and analytical quantification of biomarkers are available on the NHANES Web site. Non-fasting samples were collected on afternoon participants and included HDL-cholesterol (direct measure; mmol/L), total cholesterol (mmol/L), and C-reactive protein (CRP). All blood samples were collected in the CLIA-certified NHAMES Mobile Examination Center (MEC) unit and sent out for analysis. Fasting blood samples were collected on participants who were examined in the morning session and included: serum insulin (pmol/L), serum glucose (mmol/L), serum triglycerides (mmol/L), and LDL-cholesterol, HDL-cholesterol (direct measure; mmol/L), and total cholesterol (mmol/L). Total cholesterol, HDL-cholesterol, and triglycerides were sent to the Johns Hopkins University Lipoprotein Analytical Laboratory for analysis. Total cholesterol was measured enzymatically in serum using Roche Hitachi equipment; LDL-cholesterol was calculated according to the Friedewald calculation only in participants with triglycerides less than or equal to 400 mg/dL; specific status codes were assigned to identify these participants. Serum glucose was assessed using the hexokinase method; insulin was assessed with ELISA. In the present analysis, each marker for MetS was evaluated separately.

### Dietary assessment

In order to accurately categorize regular intake behavior, participant FFQ responses pertaining to tea consumption were analyzed against both days of 24-h recall data. The USDA Food and Nutrition Database, versions 2.0 and 3.0 were used to process NHANES dietary data intake and evaluate tea consumption. Iced tea consumption included prepared bottled iced tea as well as iced tea made from powder or tea bags. These categories were based on the combined responses to FFQ questions regarding tea intake along with 24-h dietary recall data. Chemically, herbal tea is not synonymous to *C. sinensis*-based tea. Therefore, for the purposes of this study, any subject that reported that they “always or almost always” consume herbal or decaffeinated tea were not considered to be tea consumers. If participants reported occasionally consuming herbal or decaffeinated tea, they were identified as an herbal tea consumer and herbal tea consumption was used as a covariate in all regression models. Other dietary variables (such as total energy intake and total caffeine intake) were obtained from the 24-h recall data.

### Statistical analysis

All data were analyzed using SAS version 9.3 (SAS Institute, Cary, NC, USA). Specific survey procedures were used in the analysis to account for sample weights, unequal selection probability, and clustered design. Analysis of the subset of fasting subjects required use of different survey weights in order to account for the specific characteristics of this subpopulation. Multivariate regression was used to evaluate the association of tea consumption with health outcomes related to obesity (e.g., body mass index, waist circumference, skinfold thickness, serum lipid levels, fasting glucose, and insulin). Sex-specific analysis was conducted to take into account the natural differences in body composition and caloric needs between men and women. Endpoints are adjusted for age, race, family income, education, smoking status, physical activity, total energy intake, total sugar intake, herbal tea consumption, and self-reported disease status. Self-reported disease status was collected during subject interview. Subjects reported if they had a history of a variety of conditions (i.e., diabetes), and each condition that is specific to the outcome measure was included in that model. For example, self-reported diabetic patient (i.e., subject reported diabetic status, but did not have a medical history of diabetes) was a covariate for models assessing fasting blood glucose; self-reported high cholesterol without a medical history of high cholesterol was included for serum lipids. Medically diagnosed conditions were excluded for corresponding variables (i.e., an individual with a medical history of diabetes was excluded from the analysis of fasting glucose and insulin, but not BMI or waist circumference). Results are presented as least-squared means and standard errors, with significance determined at $P < 0.05$. The procedures of this secondary data analysis were approved by the Institutional Review Board at The Pennsylvania State University.

## Results

### Subject demographics

Demographic characteristics are presented in Table 1. The majority of this sample of US adults were white (76 %), and racial breakdown was similar to the US population. Approximately two-thirds of the population was overweight or obese. In this sample of US adults, 57 % ($n = 3{,}506$) reported some sort of hot tea consumption and 9 % ($n = 603$) consumed hot tea daily (Table 1). In contrast, 70 % ($n = 4{,}244$) reported consumption of iced tea. In order to evaluate the relationship between tea and body weight independently of other dietary factors, macronutrient intake, energy intake, caffeine intake, and percentage of dietary fat were also examined. No significant differences in caffeine intake or macronutrient intake were observed between any of the categories of hot tea or iced tea consumption. Women who consumed multiple cups of hot tea daily had significantly higher total energy intake than non-consumers; men who consumed hot tea daily had significantly lower total energy intake and lower sugar intake than non-consumers; as such, total energy and total sugar intake were included as covariates in all regression models. Additionally, men who consumed multiple cups of hot tea daily had significantly lower alcohol intake than non-consumers, and inversely, women who were infrequent hot tea had significantly higher alcohol intake than non-consumers; as such, alcohol was also included in all regression models.

### Markers of body weight and body fatness

When examining the association between hot tea and various anthropometric measures, tea consumption was inversely associated with BMI in both men and women after controlling for age, race, income, education, smoking status, total energy intake, sugar intake, alcohol intake, herbal tea consumption, and physical activity (Table 2). A linear decrease in BMI was observed in both sexes: women in the highest category of tea consumption had the lowest BMI (26.2 vs. 28.5 for non-consumers); the same relationship was observed in men (25.4 vs. 27.9). A decrease in waist circumference was observed in both men and women; however, a stronger association was found among men.

In contrast, iced tea consumption was associated with an significant increase in waist circumference and BMI in women, even after controlling for age, race, income, education, smoking status, total energy intake, sugar intake, alcohol intake, herbal tea consumption, and physical activity. In men, non-consumers had significantly lower BMI and WC than men who consumed multiple cups of iced tea daily, but no other relationships existed. Additionally, subscapular skinfold thickness increased as iced tea consumption increased in both sexes (Table 2). Neither hot tea nor iced tea was not correlated with total energy intake ($r^2 = 0.11$ and 0.27, respectively).

### Markers of glycemic status, dyslipidemia, and inflammation

Hot tea consumption was inversely related to fasting glucose in women (Table 3), but not in men. No relationship between fasting glucose and iced tea consumption was observed in either sex. No relationship between fasting insulin and consumption of either type of tea was observed in men.

Regarding tea consumption and lipid profiles, different associations were observed in men and women. There was no association in any markers of dyslipidemia (HDL, LDL–cholesterol, or triglycerides) and hot tea consumption in women. In contrast, there was a significant decrease in serum HDL-cholesterol levels and serum triglycerides in women as iced tea consumption increased.

Men who reported consuming multiple cups of hot tea a day had significantly higher serum HDL-cholesterol levels and significantly lower triglycerides than non-consumers (Table 3). No significant associations were observed in any of the lipid markers and iced tea consumption in men.

There was a significant negative association between hot tea consumption and C-reactive protein in both men and women ($P$ trend, <0.001 for men and 0.01 for women). By contrast, there was no association between iced tea consumption and serum C-reactive protein in either men or women.

## Discussion

In this cross-sectional analysis of a nationally representative sample of US adults, hot tea and iced tea consumption were

**Table 1** Subject demographics

| | Sample $n^a$ | Population $N^b$ | Population $\%^b$ |
|---|---|---|---|
| Sex | | | |
| Female | 3,366 | 82,322,276 | 53.7 |
| Male | 3,106 | 70,919,467 | 46.3 |
| Race[c] | | | |
| NH-white | 3,521 | 115,735,040 | 75.5 |
| NH-black | 1,337 | 15,214,801 | 9.9 |
| Mex-Am | 1,169 | 9,980,460 | 6.5 |
| Other | 445 | 12,311,442 | 8.0 |
| Age, year | | | |
| 18–24 | 1,036 | 17,482,569 | 11.4 |
| 25–39 | 1,342 | 37,235,955 | 24.3 |
| 40–55 | 1,616 | 49,823,595 | 32.5 |
| 55–70 | 1,330 | 31,590,625 | 20.6 |
| >70 | 1,148 | 17,109,000 | 11.2 |
| Education level | | | |
| High school or less | 1,640 | 23,861,301 | 15.6 |
| High school grad/GED | 1,725 | 41,758,807 | 27.3 |
| Some college or AA degree | 1,858 | 47,755,846 | 31.2 |
| College graduate or above | 1,244 | 39,807,061 | 26.0 |
| Adjusted income[d] | | | |
| PIR <130 % | 1,955 | 32,949,458 | 21.5 |
| 130 ≤ PIR ≤ 350 % | 2,429 | 54,614,352 | 35.6 |
| PIR >350 % | 2,088 | 65,677,933 | 42.9 |
| Weight status[e] | | | |
| Lean | 2,236 | 53,730,627 | 35.1 |
| Overweight | 2,136 | 50,460,748 | 32.9 |
| Obese | 2,100 | 49,050,369 | 32.0 |
| Smoking status | | | |
| Never smoker | 3,257 | 75,498,561 | 50.1 |
| Current smoker | 1,285 | 35,582,320 | 23.6 |
| Ever smoker (>100 cigarettes) | 1,620 | 39,567,641 | 26.3 |
| Survey cycle | | | |
| 2003–2004 | 3,419 | 78,691,139 | 51.4 |
| 2005–2006 | 3,053 | 74,550,605 | 48.6 |
| Hot tea consumption | | | |
| Non-consumer | 2,921 | 66,732,051 | 43.8 |
| Infrequent (1 c/week or less) | 2,258 | 55,891,605 | 36.7 |
| Weekly, but not daily (2–6 c/week) | 645 | 15,583,670 | 10.2 |
| Daily | 342 | 7,230,135 | 4.7 |
| Multiple cups/day | 261 | 6,884,454 | 4.5 |
| Iced tea consumption | | | |
| Non-consumer | 2,166 | 46,239,277 | 30.4 |
| Infrequent (1 c/week or less) | 2,336 | 56,551,181 | 37.2 |
| Weekly, but not daily (2–6 c/week) | 1,082 | 27,884,952 | 18.4 |
| Daily | 294 | 6,962,165 | 4.6 |
| Multiple cups/day | 532 | 14,236,463 | 9.4 |

[a] Sample *n* based on cell counts

[b] Population *N* and percentages based on NHANES survey weights and represents that population of non-institutionalized US adult residents

[c] Race categories: NH-white, non-Hispanic white; NH-black, non-Hispanic black, Mex-Amer, Mexican–American; other

[d] Adjusted income level based on poverty/income ratio adjusted for household size

[e] Weight status based on 2000 CDC guidelines: lean, BMI <25, overweight, BMI 25–30; obese BMI >30

associated with various markers for obesity and metabolic syndrome; however, the association differed by tea type (hot vs. iced). Perhaps, one of the most interesting findings in this paper was the opposing relationships between health outcomes and hot and iced tea consumption. In this sample of adults, approximately 70 % consumed iced tea while 56 % consumed hot tea. Typically, hot tea has higher antioxidant content and often lower sugar content than iced tea; hot tea is typically consumed in a smaller portion than iced tea, therefore exacerbating the sugar/antioxidant relationship [21]. As with other studies, the present study found that adults (men and women) who regularly consumed hot tea were leaner than non-consumers, having a lower BMI and waist circumference. This relationship was observed after controlling for several factors.

One possible theory for the opposite relationship between hot tea consumption and obesity may be that tea consumers have higher intake of caffeine than non-consumers, although non-consumers may be coffee drinkers. Previous studies have indicated caffeine intake affects metabolic rate and energy expenditure, and therefore may influence weight status [22], and some studies suggest that the beneficial effects of tea consumption are derived from the caffeine content. In a Dutch weight-loss study, no difference in weight loss was observed between women on a hypocaloric diet supplemented with either green tea or caffeine, suggesting that caffeine may play a critical role in the weight-loss effects of tea [23]. Other intervention studies, however, have demonstrated that decaffeinated green tea and pure green tea catechins exert weight-loss effects [12, 14]. In our sample, tea consumption was not related to total caffeine intake ($P$ trend = 0.27), a finding which may support the notion that the polyphenolic compounds in tea have effects on body weight. A recent review indicated that the benefits of green tea may come from both caffeine and the catechins found in green tea [24]. Future

**Table 2** Anthropometric characteristics of tea consumers

| | Hot tea | | | | Iced tea | | | |
|---|---|---|---|---|---|---|---|---|
| | Men | | Women | | Men | | Women | |
| | LS Mean ± SE | *P* | LS Mean ± SE | *P* | LS Mean ± SE | *P* | LS Mean ± SE | *P* |
| Body mass index (kg/m$^2$) | | | | | | | | |
| Non-consumer | 27.9 ± 0.3 | Ref. | 28.5 ± 0.4 | Ref. | 26.8 ± 0.5 | Ref. | 27.1 ± 0.5 | Ref. |
| Infrequent consumer (1 c/week or less) | 27.3 ± 0.4 | 0.08 | 28.1 ± 0.4 | 0.35 | 26.8 ± 0.5 | 0.99 | 27.2 ± 0.5 | 0.84 |
| Weekly, but not daily (2–6 c/week) | 26.6 ± 0.5 | 0.02 | 27.0 ± 0.4 | 0.01 | 27.8 ± 0.5 | 0.04 | 29.1 ± 0.9 | 0.003 |
| Daily | 27.4 ± 0.5 | 0.34 | 27.2 ± 0.8 | 0.09 | 27.0 ± 0.8 | 0.8 | 29.4 ± 1.0 | 0.02 |
| Multiple cups/day | 25.4 ± 0.6 | 0.0001 | 26.2 ± 0.6 | 0.005 | 28.3 ± 0.9 | 0.08 | 29.5 ± 0.8 | 0.004 |
| Waist circumference (cm) | | | | | | | | |
| Non-consumer | 99.8 ± 0.8 | Ref. | 94.4 ± 0.8 | Ref. | 95.5 ± 1.0 | Ref. | 91.0 ± 0.9 | Ref. |
| Infrequent consumer (1 c/week or less) | 97.4 ± 0.9 | 0.003 | 93.8 ± 0.9 | 0.55 | 95.9 ± 1.2 | 0.73 | 91.9 ± 1.3 | 0.41 |
| Weekly, but not daily (2–6 c/week) | 95.2 ± 1.2 | 0.0007 | 91.7 ± 0.8 | 0.03 | 98.8 ± 1.3 | 0.004 | 95.4 ± 1.8 | 0.01 |
| Daily | 96.5 ± 1.5 | 0.04 | 91.0 ± 1.7 | 0.08 | 95.8 ± 2.3 | 0.91 | 95.7 ± 1.5 | 0.01 |
| Multiple cups/day | 93.0 ± 1.6 | 0.0004 | 89.2 ± 1.6 | 0.004 | 100.4 ± 2.5 | 0.03 | 98.3 ± 1.9 | 0.0002 |
| Tricep skinfold (mm) | | | | | | | | |
| Non-consumer | 15.5 ± 0.5 | Ref. | 22.6 ± 0.7 | Ref. | 14.1 ± 0.5 | Ref. | 21.5 ± 0.7 | Ref. |
| Infrequent consumer (1 c/week or less) | 15.0 ± 0.6 | 0.15 | 22.6 ± 0.6 | 0.97 | 13.0 ± 0.5 | 0.02 | 22.4 ± 0.7 | 0.1 |
| Weekly, but not daily (2–6 c/week) | 14.4 ± 0.8 | 0.15 | 21.9 ± 1 | 0.46 | 15.0 ± 0.8 | 0.05 | 23.9 ± 0.8 | 0.02 |
| Daily | 15.4 ± 0.9 | 0.96 | 21.9 ± 1.1 | 0.54 | 13.1 ± 0.7 | 0.12 | 23.5 ± 1 | 0.08 |
| Multiple cups/day | 13.6 ± 1.1 | 0.008 | 20.2 ± 1.4 | 0.06 | 14.4 ± 0.9 | 0.71 | 22.5 ± 0.9 | 0.25 |
| Subscapular skinfold (mm) | | | | | | | | |
| Non-consumer | 18.2 ± 0.5 | Ref. | 20.3 ± 0.7 | Ref. | 17.5 ± 0.7 | Ref. | 19.6 ± 0.6 | Ref. |
| Infrequent consumer (1 c/week or less) | 18.6 ± 0.5 | 0.43 | 20.7 ± 0.6 | 0.64 | 18.7 ± 0.5 | 0.18 | 20.3 ± 0.6 | 0.07 |
| Weekly, but not daily (2–6 c/week) | 17.3 ± 0.8 | 0.35 | 19.6 ± 1.4 | 0.55 | 18.8 ± 0.5 | 0.06 | 20.2 ± 1.0 | 0.49 |
| Daily | 20.0 ± 1.5 | 0.19 | 20.2 ± 1.8 | 0.94 | 18.5 ± 1.0 | 0.49 | 23.0 ± 1.3 | 0.02 |
| Multiple cups/day | 16.9 ± 1.2 | 0.37 | 18.7 ± 1.4 | 0.12 | 20.3 ± 1.1 | 0.05 | 22.2 ± 1.1 | 0.05 |

Results presented as least-squared means adjusted for age, race, education, smoking status, household poverty/income ratio, physical activity, herbal tea consumption, alcohol consumption, total energy intake, total sugar intake

observational and interventional studies in a longitudinal setting are needed to determine the interactions between caffeine and the other components in tea. Skinfold thickness was also lower in men who consumed multiple cups of hot tea daily compared to non-consumers. This is important, since emerging evidence suggests that elevated body fatness, particularly visceral adipose, may be a more significant risk factor for MetS than BMI or WC [25]. Further, these results are in agreement with laboratory studies showing that tea polyphenols may affect both dietary fat absorption (decrease) and fat utilization (increase) in animal models [9].

In contrast to hot tea consumption, iced tea consumption was associated with higher BMI and greater markers of body fatness (WC, skinfold thickness), especially in women. This relationship was observed even after adjusting for energy intake and controlling for total sugar intake, since Americans typically consumed sweetened iced tea. Several studies have suggested a relationship between sugar-sweetened beverage consumption, obesity, and MetS [26, 27]. In the present study, the relationship between iced tea consumption and obesity may be related to other dietary factors. Iced tea is most commonly consumed in the southern United States, where obesity rates are higher than the national average according to recent survey statistics (http://www.cdc.gov/mmwr/). The association between iced tea consumption and markers for obesity may therefore be due in part to this phenomenon.

In addition to body weight, hot tea consumption was found to be inversely associated with various glycemic

**Table 3** Tea consumption and biomarkers for MetS in US adults

| | Hot tea | | | | Iced tea | | | |
|---|---|---|---|---|---|---|---|---|
| | Men | | Women | | Men | | Women | |
| | LS Mean ± SE | *P* | LS Mean ± SE | *P* | LS Mean ± SE | *P* | LS Mean ± SE | *P* |
| Glucose, mmol/L[a] | | | | | | | | |
| Non-consumer | 6.9 ± 0.2 | Ref. | 6.6 ± 0.2 | Ref. | 7.0 ± 0.16 | Ref. | 6.5 ± 0.2 | Ref. |
| Infrequent (1 c/week or less) | 7.1 ± 0.2 | 0.24 | 6.5 ± 0.2 | 0.06 | 7.0 ± 0.18 | 0.76 | 6.6 ± 0.2 | 0.02 |
| Weekly, but not daily (2–6 c/week) | 6.9 ± 0.2 | 0.76 | 6.6 ± 0.2 | 0.97 | 6.9 ± 0.17 | 0.6 | 6.6 ± 0.2 | 0.03 |
| Daily | 7.0 ± 0.2 | 0.73 | 6.5 ± 0.2 | 0.32 | 6.8 ± 0.3 | 0.63 | 6.5 ± 0.2 | 0.74 |
| Multiple cups/day | 6.6 ± 0.2 | 0.14 | 6.4 ± 0.2 | 0.01 | 7.0 ± 0.22 | 0.86 | 6.4 ± 0.2 | 0.9 |
| Insulin, pmol/L[a] | | | | | | | | |
| Non-consumer | 87.9 ± 7.4 | Ref. | 86.6 ± 6.9 | Ref. | 81.3 ± 6.04 | Ref. | 74.6 ± 5.31 | Ref. |
| Infrequent (1 c/week or less) | 75.2 ± 8.0 | 0.003 | 82.6 ± 5.0 | 0.5 | 68.4 ± 8.94 | 0.09 | 82.4 ± 5.2 | 0.05 |
| Weekly, but not daily (2–6 c/week) | 62.6 ± 8.8 | 0.01 | 83.1 ± 6.1 | 0.6 | 84.8 ± 11.05 | 0.71 | 98.2 ± 7.42 | 0.001 |
| Daily | 84.8 ± 12.7 | 0.77 | 74.6 ± 6.2 | 0.21 | 64.1 ± 7.59 | 0.03 | 91.1 ± 8.34 | 0.06 |
| Multiple cups/day | 62.5 ± 13.6 | 0.09 | 74.4 ± 7.1 | 0.05 | 69.8 ± 8.01 | 0.06 | 95.7 ± 8.2 | 0.002 |
| C-reactive protein, mg/L[b] | | | | | | | | |
| Non-consumer | 3.9 ± 0.2 | Ref. | 5.7 ± 0.6 | Ref. | 2.7 ± 0.4 | Ref. | 5.3 ± 0.4 | Ref. |
| Infrequent (1 c/week or less) | 3.0 ± 0.5 | 0.02 | 4.4 ± 0.6 | 0.03 | 2.9 ± 0.5 | 0.44 | 4.2 ± 0.3 | 0.05 |
| Weekly, but not daily (2–6 c/week) | 2.9 ± 0.4 | 0.01 | 3.8 ± 0.7 | 0.01 | 3.3 ± 0.5 | 0.03 | 5.3 ± 0.6 | 0.95 |
| Daily | 2.5 ± 0.5 | 0.01 | 3.8 ± 0.7 | 0.02 | 6.4 ± 2.6 | 0.21 | 4.1 ± 0.5 | 0.06 |
| Multiple cups/day | 2.3 ± 0.4 | <0.0001 | 3.2 ± 0.4 | 0.002 | 3.3 ± 0.8 | 0.27 | 4.5 ± 0.4 | 0.23 |
| Total cholesterol, mmol/L[b] | | | | | | | | |
| Non-consumer | 4.9 ± 0.06 | Ref. | 5.2 ± 0.1 | Ref. | 4.9 ± 0.1 | Ref. | 5.1 ± 0.1 | Ref. |
| Infrequent (1 c/week or less) | 4.8 ± 0.06 | 0.28 | 5.1 ± 0.1 | 0.40 | 4.9 ± 0.1 | 0.91 | 5.1 ± 0.1 | 0.77 |
| Weekly, but not daily (2–6 c/week) | 4.9 ± 0.10 | 0.72 | 5.0 ± 0.1 | 0.09 | 4.9 ± 0.1 | 0.93 | 5.1 ± 0.1 | 0.99 |
| Daily | 5.1 ± 0.14 | 0.3 | 5.1 ± 0.1 | 0.79 | 5.1 ± 0.2 | 0.28 | 5.3 ± 0.1 | 0.07 |
| Multiple cups/day | 4.8 ± 0.10 | 0.41 | 5.2 ± 0.1 | 0.52 | 5.0 ± 0.1 | 0.36 | 5.1 ± 0.1 | 0.54 |
| HDL-cholesterol, mmol/L[b] | | | | | | | | |
| Non-consumer | 1.3 ± 0.02 | Ref. | 1.5 ± 0.02 | Ref. | 1.3 ± 0.03 | Ref. | 1.6 ± 0.03 | Ref. |
| Infrequent (1 c/week or less) | 1.3 ± 0.02 | 0.88 | 1.5 ± 0.02 | 0.81 | 1.3 ± 0.03 | 0.27 | 1.6 ± 0.03 | 0.08 |
| Weekly, but not daily (2–6 c/week) | 1.3 ± 0.03 | 0.38 | 1.6 ± 0.03 | 0.34 | 1.2 ± 0.03 | 0.01 | 1.5 ± 0.02 | <.0001 |
| Daily | 1.2 ± 0.04 | 0.22 | 1.5 ± 0.04 | 0.91 | 1.2 ± 0.05 | 0.26 | 1.5 ± 0.04 | 0.04 |
| Multiple cups/day | 1.4 ± 0.06 | 0.02 | 1.7 ± 0.06 | 0.07 | 1.2 ± 0.05 | 0.22 | 1.4 ± 0.03 | 0.0001 |
| LDL-cholesterol, mmol/L | | | | | | | | |
| Non-consumer | 3.0 ± 0.1 | Ref. | 2.8 ± 0.1 | Ref. | 3.0 ± 0.1 | Ref. | 2.7 ± 0.1 | Ref. |
| Infrequent (1 c/week or less) | 2.9 ± 0.1 | 0.07 | 2.8 ± 0.1 | 0.23 | 3.0 ± 0.1 | 0.98 | 2.8 ± 0.1 | 0.36 |
| Weekly, but not daily (2–6 c/week) | 3.0 ± 0.1 | 0.75 | 2.7 ± 0.1 | 0.59 | 2.8 ± 0.1 | 0.10 | 2.7 ± 0.1 | 0.94 |
| Daily | 2.7 ± 0.1 | 0.05 | 3.0 ± 0.1 | 0.06 | 3.2 ± 0.2 | 0.13 | 3.2 ± 0.2 | 0.04 |
| Multiple cups/day | 3.3 ± 0.2 | 0.24 | 2.7 ± 0.1 | 0.66 | 3.1 ± 0.1 | 0.49 | 2.8 ± 0.1 | 0.31 |
| Triglycerides, mmol/L | | | | | | | | |
| Non-consumer | 1.8 ± 0.2 | Ref. | 1.5 ± 0.1 | Ref. | 1.7 ± 0.2 | Ref. | 1.4 ± 0.1 | Ref. |
| Infrequent (1 c/week or less) | 1.7 ± 0.1 | 0.59 | 1.6 ± 0.1 | 0.16 | 1.7 ± 0.1 | 0.75 | 1.5 ± 0.1 | 0.19 |
| Weekly, but not daily (2–6 c/week) | 1.6 ± 0.2 | 0.23 | 1.6 ± 0.1 | 0.49 | 1.7 ± 0.2 | 0.81 | 1.6 ± 0.1 | 0.02 |
| Daily | 1.6 ± 0.2 | 0.25 | 1.6 ± 0.1 | 0.40 | 1.5 ± 0.3 | 0.23 | 1.8 ± 0.2 | 0.04 |
| Multiple cups/day | 1.2 ± 0.2 | 0.01 | 1.5 ± 0.1 | 0.61 | 1.6 ± 0.2 | 0.52 | 1.9 ± 0.1 | 0.01 |

Results presented as least-squared means of fasting samples adjusted for age, race, education, smoking status, household poverty/income ratio, physical activity, herbal tea consumption, alcohol consumption, total energy intake, and total sugar intake

[a] Fasting glucose, insulin values also adjusted for self-reported diabetic status

[b] Total cholesterol, HDL-cholesterol, and C-reactive protein were collected as non-fasting samples by the NHANES

biomarkers, representing a decreased in MetS risk. Although previous intervention studies aimed at improving glycemic parameters have generally seen effects on fasting blood glucose, less dramatic (or no) effects on fasting plasma insulin have been reported (reviewed in [28]). Daily tea consumption was associated with lower fasting plasma insulin levels in both men and women. Interestingly, although men who were daily tea consumers exhibited improved fasting blood glucose levels, this association was not seen in women. The lack of association may be due in part to the healthy levels of fasting glucose in women. The mean glucose level for women in all categories of tea consumption fell within the healthy range, thus any statistically significant difference would not have been clinically meaningful.

The relationship between hot tea consumption and lipid profiles was mixed. There was no association with hot tea consumption and any lipid markers in women. In men, hot tea consumption was not associated with serum LDL-cholesterol or total cholesterol; however, men who reported consuming multiple cups of hot tea daily had significantly higher serum HDL-cholesterol. Increased HDL-cholesterol levels are associated with decreased risk of cardiovascular events [29]. These results are not consistent with the conclusions of a recent meta-analysis of human intervention studies with green tea [30]. An analysis of 14 randomized controlled trials found that green tea treatment was associated with decreased plasma triglycerides and LDL-cholesterol, whereas there was no significant effect on plasma HDL-cholesterol. In the meta-analysis, green tea treatment was used exclusively; however, in the current study, adults consumed a variety of types of hot tea (green, black, and oolong), and the relationship between plasma lipid levels was derived from cross-sectional self-reported observations, not treatment observation. In the present study, iced tea consumption was not related to any lipid measures in men; however, increased iced tea consumption was associated with higher triglycerides and lower HDL-cholesterol in women. This suggests that iced tea consumption may be a marker for a different dietary pattern that may be associated with poorer health outcomes.

The anti-inflammatory effects of tea have been demonstrated in a number of laboratory models involving obesity, ulcerative colitis, and skin carcinogenesis [8, 31, 32]. In the present study, hot tea consumers had lower levels of plasma CRP compared to non-consumers of both sexes, whereas iced tea consumers had significantly higher levels of CRP compared to non-consumers. CRP is a marker of systemic inflammation, and elevated CRP levels are associated with increased risk for cardiovascular events [33]. The results of our study suggest that hot tea consumption may reduce the risk of cardiovascular events, although the body of epidemiological data on the cardioprotective benefits of tea consumption remains mixed [28].

Our study has the following limitations. First, the analysis is cross-sectional in nature. Though the associations found are interesting, it is notable that population associations do not in any way indicate causation or causality. It is possible that there is a reporting bias in the non-consumer group; the higher prevalence of overweight and obese individuals in the non-consumer group may make this group more likely to contain under-reporters. Several studies have shown that overweight and obese persons are likely to underreport intake during dietary recall [34, 35], representing one potential limitation of our study. Additionally, classification of tea drinkers is somewhat more difficult using cross-sectional data; however, our combined use of both FFQ and 2 24-h food records provides a more accurate assessment of usual intake than either parameter alone, which sets this study apart from other recently published findings on the same topic [17]. By combining data on episodic tea consumption (from 24-h recall), we were able to compare responses with regular tea consumption (from FFQ data) and confirm that participants reporting multiple cups of tea/day on the FFQ also reported multiple cups of tea during their 24-h recall.

In conclusion, we describe for the first time the relationship between consumption of hot and iced tea and markers for MetS in a representative population of US adults. We report a significant negative association between hot tea consumption, obesity, and inflammation in both men and women. The opposite association was observed with iced tea consumers, as iced tea consumption was associated with an increase in BMI, waist circumference, and inflammatory markers in adults. This finding demonstrates that the health benefits of tea consumption may occur only when tea is consumed in a traditional manner, and that iced tea may provide no health benefit to consumers, especially when sweetened. These results support the potential of tea as a modulator of body weight and indicate the need for further controlled, intervention studies to compare the effects of black, oolong, and green tea on body weight and body fat.

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