Effects on blood pressure of drinking green and black tea

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Background **The flavonoid components of tea have been associated in epidemiological studies with a decreased risk of cardiovascular disease. Flavonoids have been shown to have antioxidant and vasodilator effects *in vitro*; we therefore postulated that drinking green or black tea attenuates the well-characterized acute pressor response to caffeine and lowers blood pressure during regular consumption.**

Objective **To determine whether green and black tea can attenuate the transient pressor effect of caffeine, or lower blood pressure during regular consumption.**

Methods **In the first study, the acute effects of four hot drinks – green tea and black tea (at a dose equivalent to four standard cups), water matched to the teas for caffeine content ('caffeine') and water – were assessed in 20 normotensive men using a Latin-Square designed study. Clinic blood pressure was measured before and 30 and 60 min after each drink had been ingested. In the second study, the effects on blood pressure of regular green and black tea ingestion were examined in 13 subjects with high-normal systolic blood pressure and mild systolic hypertension (systolic blood pressure in the range 130–150 mmHg) using a three-period crossover study. Five cups per day of green tea, black tea and caffeine (in hot water and matched to the teas) were consumed for 7 days each, in random order. Twenty-four hour ambulatory blood pressure was measured at the end of each seven-day intervention. Results are presented as means and 95% confidence intervals (CI).**

Results **An acute pressor response to caffeine was observed. Relative to caffeine, there were further acute increases in systolic and diastolic blood pressure at 30 min among those drinking green tea [5.5 mmHg (95%CI −1.4 to 12.4) and 3.1 mmHg (95%CI −0.1 to 6.3), respectively] and black tea [10.7 mmHg (95%CI 4.0 to 17.4) and 5.1 mmHg (95%CI 1.8 to 8.4), respectively]. The changes in blood pressure at 60 min were not significant. The effect on 24-h ambulatory systolic and diastolic blood pressure of regular drinking of green tea [increases of 1.7 mmHg (95%CI −1.6 to 5.0) and 0.9 mmHg (95%CI −1.3 to 3.1), respectively] or black tea [increase of 0.7 mmHg (95%CI −2.6 to 4.0) and decrease of 0.7 mmHg (95%CI −2.9 to 1.5), respectively] was not significant relative to caffeine.**

Conclusions **Contrary to our initial hypothesis, tea ingestion caused larger acute increases in blood pressure than caffeine alone. However, any acute effects of tea on blood pressure did not translate into significant alterations in ambulatory blood pressure during regular tea consumption. *J Hypertens* 1999, 17:457–463 © Lippincott Williams & Wilkins.**

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Introduction

We describe here the results of two related studies examining the effects of acute and short-term regular ingestion of green and black tea on blood pressure levels. Epidemiological studies have suggested that both black tea and flavonoids that can be derived from green and black tea may protect against cardiovascular disease [1,2]. Therefore, the physiological effects of tea and its components on cardiovascular disease risk factors such as blood pressure are of interest. Tea, which contains caffeine at about 3% of dry weight and polyphenolic compounds at about 40% of dry weight [3], makes a potentially significant contribution to the total intake of caffeine and polyphenolics including flavonoids. Despite this, there has been remarkably little research on the effects of tea ingestion on blood pressure.

Ingestion of caffeine results in a transient increase in blood pressure in subjects who have avoided caffeine for 12 h or more [4,5]. Ingesting tea containing caffeine also induces a transient increase in blood pressure [6].

However, extracts of tea [7] and flavonoids found in tea [8] have been shown to have vasodilator effects *in vitro*. Therefore, the possible effect of polyphenolic components of tea on any acute blood pressure response warrant further investigation.

The results of the few studies investigating the relationship between regular tea consumption and blood pressure have been inconsistent [9–13]. In a cohort of Norwegian men and women, higher consumption of black tea was associated with lower systolic blood pressure (SBP) [9]. However, in a 4-week randomized, controlled, crossover trial in normotensive men and women, drinking six mugs of black tea daily had no significant effect on clinic measured blood pressure [10]. Moreover, in older treated hypertensive subjects, the postprandial falls in SBP were attenuated by black tea consumption [11], although no significant alteration in 24-h ambulatory blood pressure was observed (Rakic, personal communication); this outcome was possibly related to the acute pressor effects of caffeine. The effects of green tea on blood pressure have not been examined in humans. Studies performed in rats suggest that green tea extracts can lower blood pressure [12–14].

It has been suggested that oxidative stress is involved in the development of raised blood pressure [15], possibly via its effects on endothelial function [16–18]. The main hypothesis tested in the two studies reported in this paper is that antioxidant [19] and vasodilatory [7,8] polyphenolics in tea can attenuate the transient pressor effect of caffeine, and lower blood pressure during regular consumption. The effects of both green and black tea on blood pressure were examined because the two types of tea have different polyphenolic compositions [20].

Methods

The project was approved by the Royal Perth Hospital ethics committee and all participants gave their informed written consent to participate in the study. Subjects were recruited from the general population in response to media advertisements. Potential volunteers were first asked to complete a screening questionnaire over the telephone. Exclusion criteria included: smoking, and having stopped smoking within the past 6 months; body mass index (BMI) $> 33\ kg/m^2$; taking medication or any dietary supplements; alcohol intake of greater than 40 g/day; a history of major illness including diabetes, heart disease, liver disease and/or renal disease; and regular tea and coffee intake averaging less than one cup per day. Eligible subjects then attended the University Department of Medicine at Royal Perth Hospital for final screening prior to participation, and the study design and requirements were explained.

Study 1: acute effects of green and black tea ingestion on blood pressure

The acute effects on blood pressure of four different hot drinks – green tea, black tea, water matched to the teas for caffeine content ('caffeine') and water – were assessed. The effects of green and black tea on blood pressure were compared with those of caffeine alone. The water control was included to enable the effects on blood pressure of caffeine alone to be ascertained.

Subjects and experimental design

Twenty healthy, non-smoking men aged between 35 and 73 years (mean 56.2 ± 1.1 years), and with BMI between 19.0 and 32.4 (mean 25.6 ± 0.8) completed a Latin-Square designed study. Familiarization blood pressure measurements were performed at the time of the screening visit. There were four clinic visits during the study, each at least 1 week apart and on the same day of the week at the same time as far as possible. Subjects consumed each of the four drinks, one at each visit, in random order – all subjects acted as their own control. The subjects were fasting and instructed not to drink tea, coffee or other caffeine-containing beverages for at least 12 h before attending the clinic for blood pressure measurements. Those involved in measuring blood pressure were blinded to which drink was consumed. Blood pressure was measured just before beginning each drink, then 30 and 60 min after completing the drink.

Preparation of tea

Four black tea bags (blended black tea) or four green tea bags (Japanese type 'Sen-Cha' tea), with a total of 7.6 g of tea leaves, were extracted with constant movement for 4 min in 400 ml of boiled water. Subjects then drank the tea over 30 min. The other drinks – 400 ml of water with caffeine content matched to the teas or 400 ml of water – were consumed hot over the same time period. The total caffeine content of each tea and the caffeine drink was 180 mg. All drinks were prepared and consumed without additives, including milk and sugar.

Blood pressure measurement

Blood pressures were measured using a Dinamap 1846SX/P oscillometric recorder (Critikon Inc., Tampa, Florida, USA) in order to minimize observer bias. Blood pressure and heart rate were recorded on the left arm on five occasions at 2-min intervals with the subjects supine. The mean of the last two measurements was used in subsequent analyses. Blood pressure measurements were not disclosed to participants during the study in order to minimize possible effects from expectation bias.

Caffeine measurement

A blood sample was taken before drinking the tea or control drinks, and at 60 min after completing the drink. Plasma was prepared, then immediately frozen at −80°C. A reversed-phase high performance liquid chromatography (HPLC) method based upon that of Setchell *et al.* [21] and described in detail previously [22] was used to quantify caffeine concentration in the tea extracts, and to measure plasma concentrations of caffeine.

Study 2: effects of regular green and black tea ingestion on blood pressure

The effects on blood pressure of the regular ingestion of green and black tea for 7 days were compared with regular ingestion of hot water with caffeine – matched to the teas – ('caffeine') using a three-period crossover study.

Subjects and experimental design

Thirteen healthy, non-smoking subjects, ten men and three postmenopausal women not taking hormone replacement therapy, were recruited. Subjects were recruited on the basis of having a high-normal range SBP or mild systolic hypertension (SBP $>$ 130 mmHg and $<$ 150 mmHg), with diastolic blood pressure (DBP) less than 100 mmHg. Their ages ranged from 25 to 72 years (mean 59.8 $\pm$ 2.6 years), and BMI ranged from 20.7 to 32.5 (mean 27.0 $\pm$ 1.1).

A randomized crossover study with three periods, each of 7 days, was performed. During the three 7-day periods, the subjects drank green tea, black tea and hot water containing caffeine at a concentration matched to that of the teas. No period of drinking hot water without caffeine was included in this study because of possible carry-over effects associated with caffeine withdrawal. Subjects consumed five 200 ml cups per day of tea or control hot drink. During the 3 weeks of intervention, subjects were instructed to cease intake of caffeine-containing beverages (except those assigned) including tea, coffee, chocolate drinks and cola, and of herbal teas. Apart from these changes, dietary intake and usual level and pattern of alcohol intake were unchanged throughout the study. Twenty-four hour ambulatory blood pressure was measured at baseline and at the completion of each 7-day intervention period.

Preparation of tea

Tea bags, containing either Japanese 'Sen-Cha' green tea or blended black tea, with 2 g of tea leaves, were allowed to infuse in boiled water for 60 s with regular movement, and squeezing before removal. The control drink was pure caffeine dissolved in boiled water. The caffeine concentration was the same for all drinks: approximately 50 mg per cup. The teas and control drinks were consumed without additives including milk or sugar. Compliance was measured by using counts of tea bags and caffeine containers.

Blood pressure

At screening, the subjects' blood pressure was assessed in the department using a Dinamap 1846SX/P oscillometric recorder (Critikon Inc.). Subjects rested for 10 min before blood pressure monitoring commenced. Blood pressure and heart rate were then measured every 2 min for 10 min with subjects in the sitting position. The mean of the last two measurements was used as the screening value.

During the study, blood pressure was assessed as 24-hour ambulatory blood pressure measurements, using an Accutracker II (Suntech, Raleigh, North Carolina, USA). Ambulatory blood pressure monitoring was performed before intervention (baseline) and at the end of each 7-day intervention. Each subject had used one Accutracker instrument throughout the study for all ambulatory blood pressure assessments. The instrument was programmed to record blood pressure every 30 min over 24 h. Subjects were instructed to continue their usual daily activities and to avoid any vigorous exercise. They kept an activity log and were asked to perform similar daily activities on each day of ambulatory blood pressure monitoring. Blood pressure measurements were not visible to the subjects. Measurements showing an error code or those with a pulse pressure of less than 20 mmHg were excluded from the analysis. Mean SBP, DBP and heart rate were calculated for each 24-h period, and mean values of waking and sleeping blood pressure and heart rate were also computed.

Statistical analysis

All statistical analyses were performed using an SPSS system (SPSS Inc., Chicago, Illinois, USA). Results are presented in the text and tables as mean and 95% confidence interval (CI) and in figures as mean $\pm$ SEM. $P < 0.05$ was considered statistically significant. General linear models were used to examine differences between treatments, with adjustments of P-values for multiple tests. Because of the dependence of the change in blood pressure on its initial level [23], post-intervention blood pressure was compared after adjustment for initial or baseline levels using general linear models. The results of these analyses are presented as mean baseline adjusted change (study 1) or difference (study 2) with 95% CI. Plasma caffeine concentrations were compared using paired t-tests and the results are presented as mean and 95% CI for the paired differences.

Results

Study 1: acute effects of green and black tea ingestion on blood pressure

The mean SBP, DBP and heart rate at baseline and at 30 and 60 min after each drink (water, caffeine, green tea and black tea) are presented in Table 1. Ingestion of caffeine resulted in acute increases in SBP and DBP of approximately 6 mmHg and 3 mmHg, respectively, at 30 and 60 min, relative to water (Table 1).

The baseline-adjusted SBP and DBP for green tea and black tea in comparison with caffeine are presented in Figure 1. Relative to caffeine, there was a significant increase in SBP of 10.7 mmHg (95%CI 4.0–17.4), and in DBP of 5.1 mmHg (95%CI 1.8–8.4) for black tea at 30 min. The increases in SBP of 5.5 mmHg (95%CI −1.4 to 12.4), and in DBP of 3.1 mmHg (95%CI −0.1 to 6.3) for green tea relative to caffeine at 30 min did not reach statistical significance. There were no significant changes in SBP or DBP for green tea and black tea relative to caffeine at 60 min. In addition, there were no significant changes in heart rate as a result of drinking green or black tea, at 30 or 60 min.

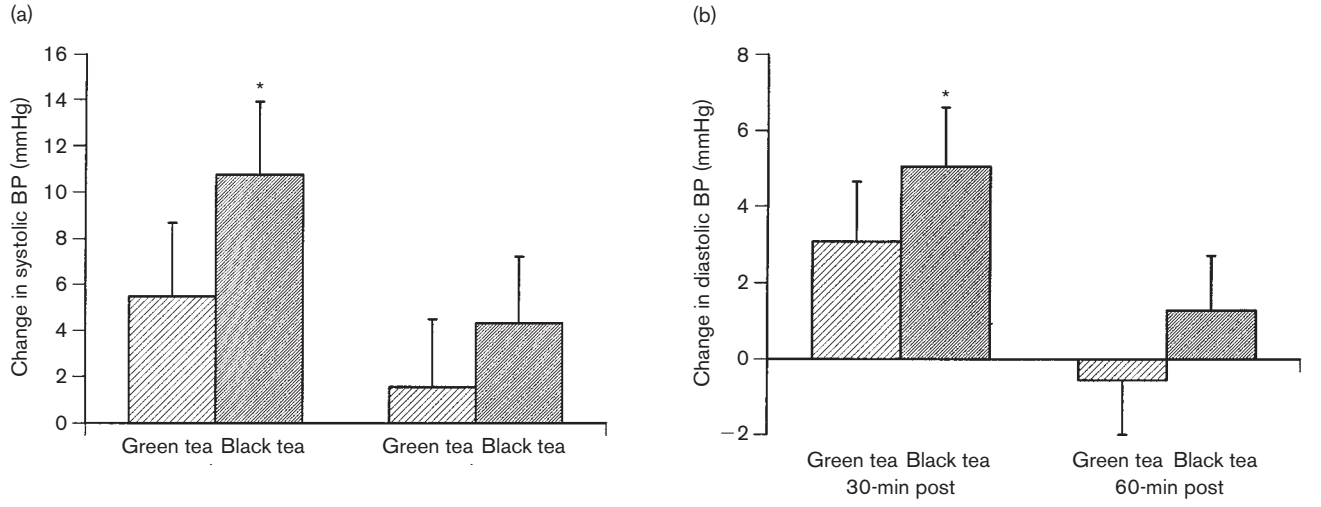
Plasma concentrations of caffeine were significantly higher 60 min after drinking caffeine [2.58 mg/l (95%CI 2.18–2.97)], green tea [2.44 mg/l (95%CI 2.06–2.81)] and black tea [2.32 mg/l (95%CI 1.86–

Table 1 **Systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate at baseline and at 30 and 60 min after drinking hot water (water), hot water with caffeine (caffeine), green tea and black tea**

	Baseline	30 min	60 min
Water			
SBP (mmHg)	113.7 (108.7–118.7)	115.1 (108.6–121.6)	115.4 (108.5–122.3)
DBP (mmHg)	67.7 (64.1–71.3)	68.4 (65.1–71.7)	69.6 (66.0–73.2)
Heart rate (beats/min)	62.8 (57.4–68.2)	59.1 (53.9–64.3)	59.5 (54.5–64.5)
Caffeine			
SBP (mmHg)	111.4 (105.7–117.1)	118.0 (112.1–123.9)	118.1 (110.8–125.4)
DBP (mmHg)	65.9 (62.1–69.7)	69.4 (65.6–73.2)	70.9 (67.1–74.7)
Heart rate (beats/min)	60.6 (56.2–65.0)	56.4 (52.6–60.2)	57.2 (55.1–59.3)
Black tea			
SBP (mmHg)	111.0 (106.6–115.4)	128.6 (119.8–137.4)	122.3 (115.3–129.3)
DBP (mmHg)	66.0 (62.9–69.1)	74.5 (71.9–78.1)	72.1 (69.0–75.2)
Heart rate (beats/min)	59.9 (56.3–63.5)	57.4 (55.3–59.5)	56.6 (53.3–59.9)
Green tea			
SBP (mmHg)	112.3 (107.3–117.3)	124.8 (116.6–133.0)	120.9 (114.2–127.6)
DBP (mmHg)	67.1 (64.7–69.5)	73.4 (69.8–77.0)	71.1 (68.4–73.8)
Heart rate (beats/min)	60.7 (58.0–63.4)	56.6 (53.0–60.2)	57.4 (54.1–60.7)

Data are presented as means and 95% confidence intervals.

Fig. 1



Baseline adjusted change in systolic blood pressure (SBP; a) and diastolic blood pressure (DBP; b) for green tea and black tea relative to caffeine at 30 and 60 min after each drink. Values are means ± SEM. * $P < 0.05$ for 30 min post-drink comparisons between black tea and caffeine after adjustment for baseline blood pressures, using general linear models.

2.78)] than those for water. However, there were no significant differences in plasma concentrations of caffeine at 60 min after drinks between caffeine and green tea [0.22 mg/l (95%CI −0.14 to 0.56)], caffeine and black tea [0.23 mg/l (95%CI −0.08 to 0.55)], or green tea and black tea [0.07 mg/l (95%CI −0.23 to 0.24)].

Study 2: effects of regular green and black tea ingestion on blood pressure

The mean 24-h ambulatory blood pressure and heart rate at baseline and at the end of each 7-day period drinking caffeine, green tea or black tea are presented in Table 2. Mean blood pressures during consumption of green and black tea, in comparison with the mean blood pressures during consumption of caffeine, for each hour of ambulatory blood pressure monitoring are presented in Figure 2.

Relative to caffeine, there was no significant effect on SBP or DBP caused by ingestion of regular green tea [increases of 1.7 mmHg (95%CI −1.6 to 5.0) and 0.9 mmHg (95%CI −1.3 to 3.1), respectively] or black tea [increase of 0.7 mmHg (95%CI −2.6 to 4.0) and decrease of 0.7 mmHg (95%CI −2.9 to 1.5), respectively] over 24 h of ambulatory blood pressure measurement. Similar analyses were performed for waking and sleeping blood pressure, and there was also no significant effect of green tea or black tea in comparison with caffeine. In addition, green or black tea did not significantly influence ambulatory heart rate.

Discussion

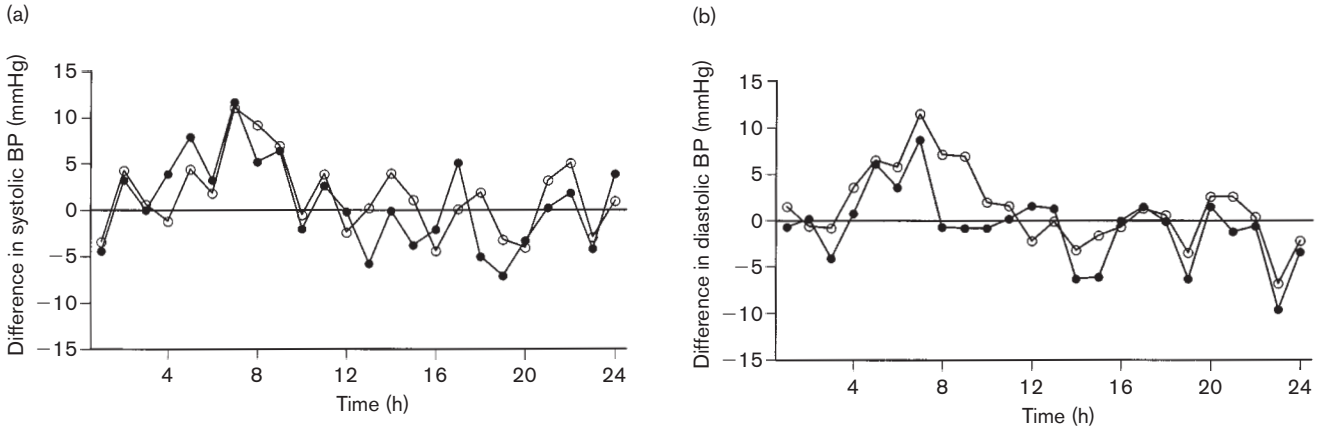
An acute increase in blood pressure occurred 30 min after drinking black tea, relative to caffeine. A similar trend in blood pressure for green tea relative to caffeine at 30 min did not reach statistical significance. In contrast, the measurement of ambulatory blood pressure during 7-day periods of regular green tea, black tea or caffeine consumption suggested that such an effect is probably transient and does not translate into longer-term pressor effects.

The observation of acute pressor effects of caffeine in the present study are consistent with previous reports [4,5], in which caffeine (3.3 mg/kg body weight) caused acute increases in SBP of 5–9 mmHg and in DBP of 3–8 mmHg. These increases were seen at 30 min after caffeine intake and were maintained beyond 60 min [4]. Our results were similar, in that 180 mg of caffeine, averaging 2.3 mg/kg body weight, caused a mean increase in blood pressure of about 6/3 mmHg at 30 and 60 min after the drink (Table 1).

Table 2 **Mean 24-hour ambulatory systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate at baseline and after five cups per day of caffeine in hot water (caffeine), green tea and black tea for 7 days each**

	Baseline	Caffeine	Green tea	Black tea
SBP (mmHg)	136.6 (134.6–138.6)	135.5 (132.2–138.8)	137.2 (135.0–139.4)	136.1 (132.8–139.4)
DBP (mmHg)	76.2 (74.7–77.7)	77.5 (75.8–79.2)	78.4 (76.9–79.9)	76.9 (75.4–78.4)
Heart rate (beats/min)	70.8 (69.3–72.3)	69.0 (67.5–70.5)	69.2 (67.7–70.7)	69.5 (68.0–71.0)

Fig. 2



Mean systolic blood pressure (SBP; a) and diastolic blood pressure (DBP; b), relative to caffeine, during consumption of green tea (○) and black tea (●) for each hour of 24-h ambulatory blood pressure measurements. There were no significant differences between green or black tea and caffeine after adjustment for baseline levels, compared using general linear models.

In our study, the possibility that other components of green and black tea may modify the acute pressor response to caffeine was examined. An additional pressor effect of black tea in comparison to caffeine alone was seen 30 min after the drinks, but not at 60 min. This suggests that either the caffeine pharmacokinetics are influenced by tea, or that other components of tea are responsible for a transient pressor effect.

The results of previous studies and the measurements of plasma concentrations of caffeine do not support the suggestion that the absorption or metabolism of caffeine is influenced by tea. The results of studies in which caffeine has been given with and without coffee [24] and grapefruit juice [25] suggest that other components of those drinks did not influence caffeine pharmacokinetics. In addition, no differences were observed in plasma concentrations of caffeine at 60 min after the drinks between the three caffeine-containing drinks. However, the significant pressor effect of black tea observed at 30 min was not observed at 60 min. Therefore, differences in caffeine absorption or metabolism between drinks, as an explanation for the acute pressor effect of black tea, cannot be ruled out.

There is little evidence available regarding the effects of components of tea other than caffeine on blood pressure. Another methylxanthine, theobromine, is present in tea at about 0.2% of dry weight [20]. Theobromine is unlikely to have contributed significantly to the pressor effect of black tea, unless its effects are considerably more potent than those of caffeine. To date, there is no evidence to suggest that this is the case. Another potentially interesting component of tea with respect to blood pressure, is theanine. Theanine is a novel amino acid found only in tea [20], but is unlikely to have contributed to the acute pressor effect of black tea. High doses of theanine have been found to lower blood pressure in spontaneously hypertensive rats [14]. The effects on blood pressure of many other components of tea, such as the polyphenols, organic acids and lipids and related compounds are not known. Therefore, the mechanism for this newly described acute pressor effect of black tea, and possibly green tea, remains unknown.

In the second study the effects of regular green and black tea consumption on blood pressure were examined using a 7-day intervention. Our approach permitted an assessment of the relevance of the acute pressor effects of tea to the ambulatory setting. In addition, it permitted the suggestion that regular tea ingestion lowers blood pressure [9,12–14], possibly via effects of vasodilator polyphenolic components of tea [7,8], to be explored. Subjects recruited to this study had high-normal range blood pressure or mild systolic hypertension, thus increasing the potential to observe changes in ambulatory blood pressure.

We found no significant effect of either green tea or black tea on ambulatory blood pressure. A controlled intervention with black tea in humans, using a similar crossover study design, also found no effect on blood pressure assessed using clinic blood pressure measurement in normotensive subjects [10]. In addition, a recent double-blind study using a quercetin supplement, at considerably higher concentrations than the quercetin concentration in green and black tea [3], reported no effect on blood pressure [26]. The result of the present study, that there was no effect on blood pressure of either green or black tea, suggests that any acute pressor effect of tea ingestion is transient.

The possibility that regular tea consumption has effects on blood pressure in other populations has not been fully explored and should not be ruled out. The population studied here included non-smokers who had high-normal blood pressures or mild systolic hypertension. The effects of tea on blood pressure may be different in different groups such as smokers, diabetics, the elderly or other groups with increased oxidative stress. In addition, longer-term interventions may demonstrate changes not seen in the current 7-day study.

In conclusion, green and black tea do not attenuate the acute pressor response to caffeine. On the contrary, there was an acute increase in blood pressure relative to caffeine 30 min after drinking black tea. A similar non-significant trend was observed for green tea. The mechanisms involved in this acute increase in blood pressure have not been evaluated. However, regular consumption of green tea or black tea over 7 days had no significant effect on ambulatory blood pressure. These results suggest that any acute effects of tea on blood pressure do not lead to significant changes in blood pressure during regular tea ingestion in subjects with moderate elevations in blood pressure.

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