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Effect of black tea consumption on radial blood pulse spectrum and cognitive health

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ABSTRACT

Black tea consumption has been proven to improve endothelial function and to lower the risk of stroke and cognitive impairment. Several effects of black tea on cardiovascular system had been surveyed. However, the black tea effect on pressure pulse spectrum remains unknown. The study was aimed to investigate the influence of black tea on radial blood pressure and Pulse Spectrum. Fourteen healthy subjects received water and single doses of black tea (0.05 g/Kg) in separate weeks. The radial blood pressure and pulse wave were measured and the pressure pulses were evaluated using harmonic analysis. This report confirmed that black tea consumption (dose = 0.05 g/Kg) significantly increased third, fifth, ($P < 0.1$), sixth, seventh, and eighth harmonics ($p < 0.05$) of radial pressure wave comparing to water control. We proposed that black tea may increase cerebral blood flow (CBF), which was deduced from the results and from the conclusions of previous studies. The results also showed that the harmonic components of pressure pulse could be the vascular kinetic index that assessed the hemodynamic status in each time frame before and after consumption of black tea.

1. Introduction

Tea is one of the most popular beverages in the world, which can inhibit the development of cancer,[1] lower the risk of cardiovascular disease,[2,3] and improve cognitive health in human.[4] Several surveys proved that black tea improved endothelial function.[5,6] The work of others supported this concept and proved that epigallocatechin gallate (EGCG), one of tea catechin polyphenols, was able to activate the endothelial nitric oxide synthesis (eNOS) via several signaling pathways.[7] The eNOS plays major role in the control of cerebral blood flow (CBF) regulation[8] and promotes the maintenance of CBF in early stages of cerebral ischemic syndromes.[9]

In spite of several studies focusing on the effect of black tea on cardiovascular system, few studies investigated the effect of tea consumption on the pressure pulse spectrum. Pulse wave analysis can be an effective method for investigate the response of the arterial system.[10] Researchers showed that arterial blood pressure drives the blood flow into the capillaries of the organ irrigated by the artery.[11,12] This phenomenon was first investigated in rats,[13] further modeled and demonstrated through tube simulation.[14] Lin Wang et al. then derived a rigorous analytic equation of the PR wave to explain the meaning of the harmonic components, the main components of arterial pressure waveform, in cardiovascular physiology.[15] In summary, the ventricular-arterial coupling system distributes the energy in proportions to the harmonic components of pressure pulse to different organs and meridians.[16,17] The local pressure pulses in the arteries and arterioles then drive the flow into capillaries.[11,18] Hence, the pattern of harmonic components could reveal the blood flow condition of organs[10] or specific meridian.[19]

Therefore, the aim of this study was to investigate the short term effects of black tea consumption on the radial pressure pulse spectrum. The harmonic analysis of radial arterial pulse wave, which was highly correlated with twelve meridians of Traditional Chinese Medicine, was used in monitoring the cardiovascular system.

2. Materials AND methods

2.1. Subjects and diet restriction

A total of 14 health subjects (11male, 3 female) aged 27–60 years, and weighted 46–92 kg were enrolled in this study. All of the subjects were nonsmokers and were not heavy drinkers of coffee, tea, or cola (less than 3 cups per day). Subjects were recruited after receiving approval from the institutional review board of the RenAi

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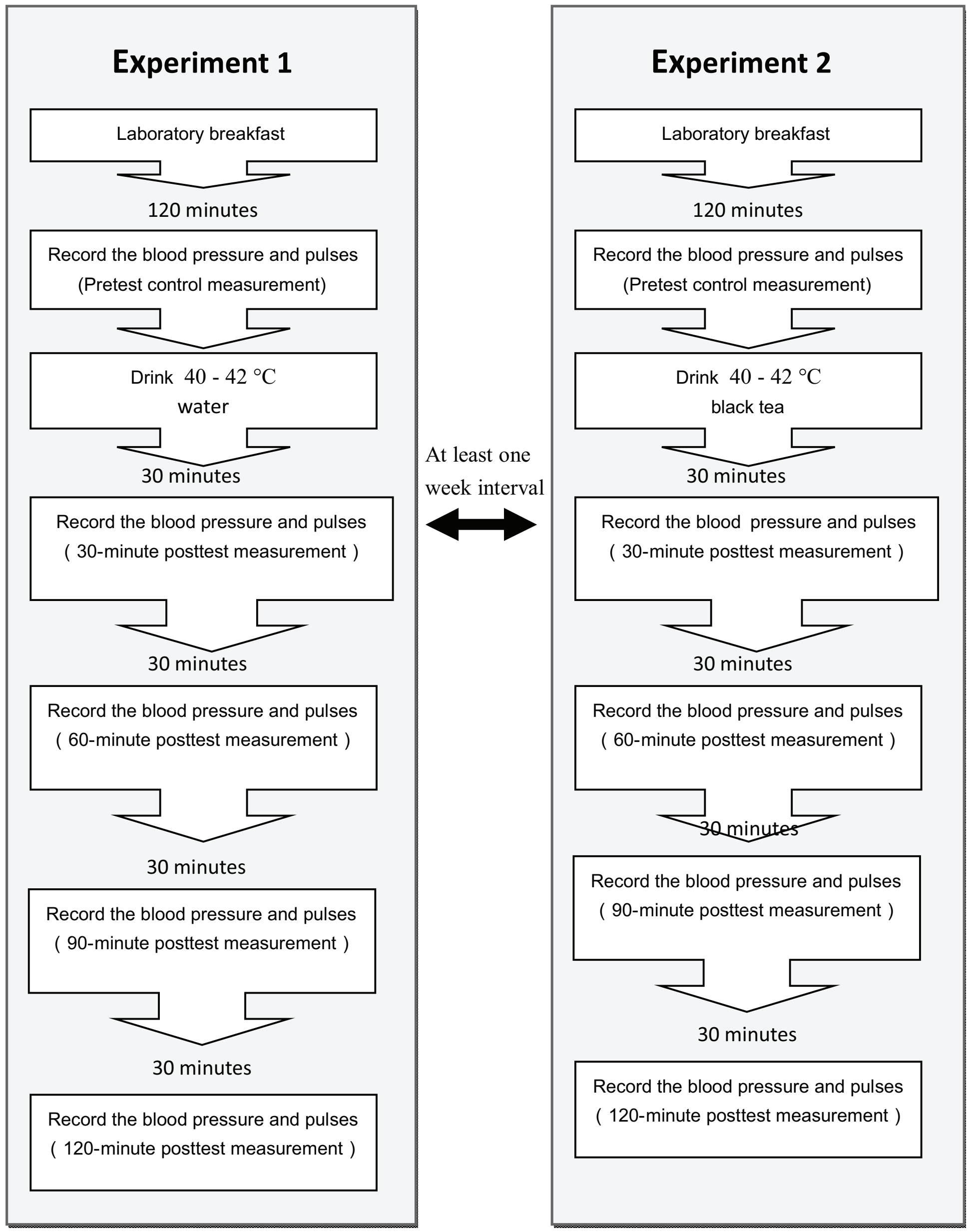

Fig. 1. Detail of experimental profiles.

Branch of Taipei City Hospital (IRB number: TCHIRB1010710). Oral and written information about the study was given. All subjects provided signed informed consent before their participation.

Diet restrictions were in place for all subjects during the course of the study. No concomitant medications (prescription, over-the-counter, or herbal) were to be administered for 3 days before the experiments. Cocoa, alcoholic, and caffeinated beverages were withheld 24 h prior to the experiment.

2.2. *Study protocol*

A self-controlled repeated measure designed study with consumption of water and black tea was performed separately in two weeks. This study aimed to evaluate the short-term effect of black tea on the radial pressure waveform in healthy human.

Experiment 1 measured the radial artery pressure wave before and after the consumption of 40–42 °C warm water, where the volume of warm water were equal to the volume of black tea needed for each subject. Experiment 2 measured the radial artery pressure pulse before and after the consumption 0.05 g/Kg dose of black tea, with at least one week interval between experiment 1 and experiment 2. Experiment 1was treated as the control treatment comparing to the black tea treatment. All the experiments were conducted in a room maintained at 23–25 °C.

In each experiment, subjects visited in the morning and we provided a standard breakfast served with egg sausage muffin and 250 ml of warm soybean milk. The first measurement was carried out at 120 min after the first bite of food as the pretest control. The treatments were performed 120 min after the first bite of food because the arterial pulse wave was relatively stable in the period.[20,21]

Each test subject received single dose of the Lipton black tea immediately after pretest measurement finished. The other four measurements were then recorded at 30 min, 60 min, 90 min, and 120 min after consuming the black tea as the posttest measurements. Totally five measurements of the radial arterial pulse wave were performed. (Fig. 1)

Table 1
Average pretest measurement values and posttest measurement values of systolic pressure (SP), diastolic pressure (DP), pulse pressure (PP = SP-DP), and heart rate (HR) in Experiment 1 (Water effect, N = 14) and in experiment 2 (Black tea effect, N = 14) separately.

	SP (mm Hg)	DP (mm Hg)	PP (mm Hg)	HR (beats/minute)
Water				
Pretest control	116 ± 4	66 ± 2	50 ± 3	78 ± 4
Posttest measurement	115 ± 4	68 ± 2	47 ± 2	76 ± 3
Black tea				
Pretest control	112 ± 3	69 ± 3	43 ± 2	80 ± 4
Posttest measurement	117 ± 4	71 ± 3	46 ± 3	75 ± 3

Data are mean ± standard error values.

The harmonic analysis was used in both Experiment 1 and Experiment 2 to compare the changes of the pressure waveforms before and after consumption of black tea and water. The effects of two Experiments on the harmonics of the pressure waveforms, blood pressure, and heart rate were compared using Student's *t*-test. The experimental procedures are similar to our previous study that focused on the coffee effect.[22]

2.3. Preparation of black tea

60 g of Lipton black tea (2 g tea bag*30 servings) was placed in the glass pot. 3000 ml of 95° C hot water was poured into the pot and the black tea was brewed for 1 min. The brewed tea was then poured into another pot for cooling down the temperature. The warm black tea was poured into several cups that matched the dose 0.05 g/Kg of black tea for subjects when the liquid were between 40–42 °C. For example, subjects with 60 kg and 90 kg weight were served 150 ml and 225 ml black tea respectively.

2.4. Blood pressure measurement

Each subject was asked to sit and rest for 10 min before all measurements. In each measurement, the blood pressure and heart rate were measured with blood pressure monitor HEM-6051 (Omron, Japan). The pulse pressure was then recorded on the right hand radial artery with a pulse wave analyzer TD01C (MII-ANN Technology, Taiwan), which has proved its reliability using artificial pulse generator.[23] The intra-observer and inter-observer reliability were also examined in the clinical test.[24] About 10–20 consecutive pressure pulses were obtained during a 12-s period.

2.5. Data acquisition and harmonic analysis

The pressure pulse data were collected from TD01C, with sampling rate of 400 data points per second. This data were than transformed into harmonic components (C_n) using Fourier transform function of the software Matlab 2008, USA. C_n is defined by following equation:

$$C_n = \frac{A_n}{A_0},$$

where A_0 is the mean value of pulse wave and A_n is nth coefficient of Fourier series of the radial arterial pulse wave. This study focused on the first ten harmonic components (C1–C10), which contained more than 95% energy of alternating signal of pressure pulse.

3. Results

Table 1 lists the averaged pretest measurement values of systolic pressure (SP), diastolic pressure (DP), pulse pressure (PP = SP-DP), and heart rate (HR) in Experiment 1and Experiment 2. Fig. 2 shows that the consumption of water and black tea both increase DP. The difference between effect of water and black tea was also non-significant. The change of SP between pretest and posttest measurement in Experiment 2 was significantly different from that in Experiment 1 ($P < 0.05$), which confirmed that black tea consumption increase SP within 120 min (Fig. 2). The change of PP between pretest and posttest measurement in Experiment 2 was also significantly different from that in Experiment 1 ($P < 0.01$). The HR decrease 6.8% averagely after black tea consumption; however, the change of HR was not significantly different from the water consumption ($P = 0.11$).

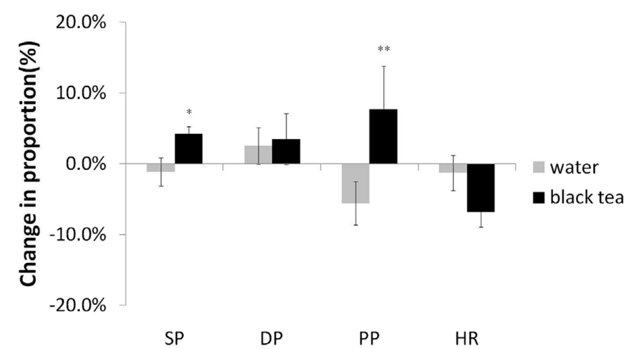

Fig. 2. Effects (n = 14) of water and black tea on systolic pressure (SP), diastolic pressure (DP), pulse pressure (PP = SP-DP), and heart rate (HR). The average four-round posttest effects are presented as percentage changes relative to the pretest controls. The error bars indicate standard errors. Single and double asterisks indicate that the effect of tea differed significantly ($p < 0.05$ and $p < 0.01$, respectively) from the effect of water.

Fig. 3 shows that the effects of black tea on different harmonic components of pressure pulse had different decay rates. For harmonic analysis, C3, C5, C6, C7, C8, C9, and C10 significantly increased more after consumption of black tea than consumption of water (Fig. 3). The black tea effect on increment of C3 and C5 maintained at peak values for about 60 min and returned to pretest level at 90 min after black tea consumption. The black tea effect on C6 to C8 maintained for about 90 min then started to decrease (Fig. 3). C9 and C10 reached the peak values at 30-min posttest measurement and returned to pretest level at 120-min posttest measurement.

4. Discussion

Consumption of black tea decreased the heart rate but did not differ significantly from consumption of warm water (Fig. 2). This phenomenon was also found in coffee-water placebo study.[22]; The black tea effect on SP differed significantly from the effect of water. This increase in SP may be partially related to the caffeine effect which was discovered in previous caffeine research[25,26] However, the consumption of black tea increased more SP than the consumption of coffee, whereas the caffeine dosage of black tea in Experiment 2 was about 1/5 of caffeine dosage in the coffee study.[22,26] Therefore, the other content of black tea might involve in the short term effect (within 120 min) on the increment of SP. The consumption of black tea increased DP slightly, which influenced less than consumption of coffee.[22] The increment of DP differed non-significantly comparing to the consumption of water.

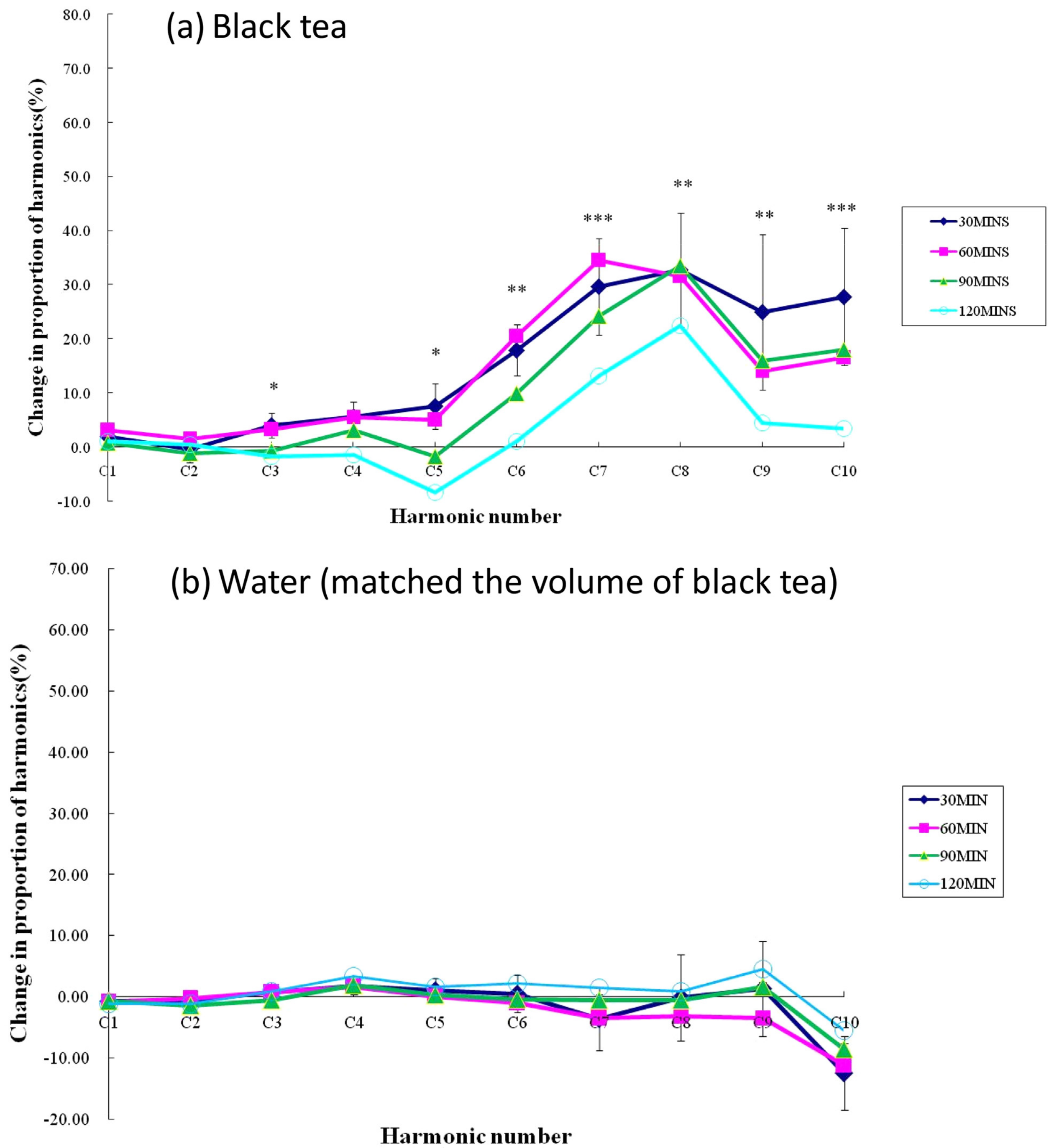

Fig. 3. Effects of (a) 0.05 g/Kg dose of black tea, n = 14 and (b) water, n = 14 on blood pressure pulse spectrum. The 30-, 60-, 90- and 120-min posttest effects were calculated as the percentage changes in the proportions of the harmonics relative to the pretest control. The error bars indicate standard errors of 30-min post tea effect on harmonics components. Single, double, and triple asterisks indicated that the effect of black tea differed significantly from the effect of water ($p < 0.1$, $p < 0.05$ and, $p < 0.01$ respectively).

The consumption of black tea increased PP significantly while the consumption of the equal volume of water decreased PP. This effect of black tea on PP was contrary to the result of coffee study[22] and thus may be caused by other components of tea. There was less possibility that the effect was caused by L-theanine since it decreased both SP and DP significantly.[27,28] Since the phenolic compounds composed majorities of the organic content of tea soups, the short-term effect on PP may be derived from the effect of catechins and their derivatives from the fermentation process, such as theaflavins, thearubigins, and gallic acids.

Hodgson et al. also pointed that black tea had an additional pressor effect on both SP and DP relative to caffeine.[29] The black tea consumption increase short-term SP and DP no matter during the early-morning and nighttime.[30] This increasing effect on SP was stronger than that on DP,[29,31] causing the increment of PP, which was consistent with our results. Therefore, among the short-term effects of black tea on blood pressure (SP, DP, and PP), caffeine effect is inevitable but not a dominant effect.

Wang et al. have pointed out that higher harmonics from C6 to C10 is correlated to the meridians that cross the head.[19] Hsiu et al. also reported that there was a significant positive correlation between C5 and CBF using laser Doppler flowmetry (R^2 = 0.5, $p < 0.01$) and that C6 and CBF were both increased after the acupuncture intervention.[32] Since the C6, C7, C8, C9, and C10 of the pressure pulse all increased after black tea consumption (dose = 0.05 g/kg), we proposed that the consumption of black tea may increase CBF. The further studies should be carried out to confirm the hypothesis. The correlation among measurements of CBF using magnetic resonance imaging,[33] ultrasound,[34] or using harmonic analysis should also be further explored and validated.

Jochmann demonstrated that consumption of black tea increases flow-mediated dilation by increasing eNOS.[35] Replenishing eNOS may be one of the reasons that tea ingestion was involved in the increment of CBF. Annick et al. further proved that catechins can improve CBF in mice study.[36] Black tea components such as catechins,[37–39] theanine[40–42] and theaflavin,[43] have been also shown that reducing infarct volume in animal models of ischemic stroke. Furthermore, the large prospective study confirmed that high black tea consumption (>4 cups of black tea daily) was associated with the reduction of stroke risk.[44] Meta-analysis of prospective studies also showed a significant inverse association between tea consumption and risk of ischemic stroke. Nevertheless, Sorond et al. found that flavanol-rich cocoa, with abundant catechins and a similar dose of caffeine (18–20 mg/cup) comparing to black tea in our experiment 2, increased CBF in healthy elderly humans.[33,45] These two research showed flavanols, including catechins, epi-catechins, and those derivatives in cocoa may have the ability to enhance the CBF. Therefore, tea-induced increment of CBF may also be one of the possible mechanisms to lower the risk of the cerebral ischemia.

In addition, Catechins and polyphenols of tea also exerted neuroprotective effects of tea due to their powerful antioxidant and anti-inflammatory properties.[46] Theaflavins from black tea were also proved potent antioxidants.[47,48] and anti-inflammatory compounds[49] There is great potential to continually survey the effect of tea components on brain circulation and its neuroprotective effect in human.

Vidyasagar et al. surveyed the black tea effect on CBF using magnetic resonance imaging and showed a reduction of CBF after taking the capsule of black tea for caffeine consumers who regularly consumed 1–5 caffeinated beverage per day.[50] The results may cause from heavy doses of caffeine in the capsule of black tea, which was about 10-fold of caffeine than what we served.[26] Work of others survey also revealed that high dose of caffeine reduced the CBF significantly.[51] The interesting thing is their decaffeinated black tea showed no significant effect on CBF, whereas the catechins improved cerebrovascular flow-mediated dilation and CBF in animal models.[36,52] The results may be attributed to different compositions and doses between black tea solid and its water extract.

The Black tea increased the higher harmonics (C6 to C10) of pressure pulse tremendously comparing to the acupuncture effect on pressure pulse.[32] The increments of C6 to C10 were much similar to the effect of famous qi-stimulated tonic herbs such as Ganoderma lucidum, Panax ginseng, and Panax quinquefolius (American ginseng)[53] which may be partially attributed to biological effects of caffeine on adenosine receptors.[22] However, the black tea in experiment 2 had only about 1/5 of caffeine but raised the higher harmonics (C6-C10 raised in 30-min) faster comparing to the coffee study. Therefore, there are other compounds besides caffeine also had influences on radial blood pulse spectrum. The effects of black tea on the increment of C3 to C10 reached maximum values ranged from 30 to 90 min and returned to pretest level at different timings (Fig. 3), which showed the different decade rates of harmonics. Thus, there may be several components of black tea influencing on different arterial beds through different mechanisms. Van der Pijl et al. reported that plasma concentration of L-theanine reached the peak value about 50 min after ingestion of L-theanine-enriched black tea,[54] while as the plasma concentration of caffeine reached peak value between 15 and 120 min.[55] In addition, the plasma concentration of catechins reached peak values ranged from 68 to 96 min.[56] Those compounds of tea influenced the blood pressure in different ways and in different durations.[28] However, the influence of specific compounds of tea on pressure pulse spectrum remained unknown. We anticipate this assay to be a starting point for discovering the mechanisms underlying tea-mediated change of pressure pulse spectrum.

In addition, the previous research showed that ingestion of spleen meridian herbs of Traditional Chinese Medicine would increase C3 of a radial pulse wave, where consumption of black tea had a similar effect but the increment of C3 in Experiment 2 was smaller than that affected by spleen meridian herbs.[57] The black tea could be an entrance to understanding the mechanisms of herbs on spleen meridian since they had the consistents effect on C3.

The waveform of arterial pressure pulse could reflect the arterial stiffness and thus correlated with aging effect using either augmented index.[58] or harmonic analysis[59] Sherebrin et al. also found the decreasing power of the harmonics of the peripheral pulse wave in elder groups using photoplethysmograph.[60] Furthermore, arterial pulse spectrum could also reflect ventricular structure, ventricular mass,[61] and oscillation status between the aorta and the kidney before and during the clamping of the renal artery.[14] Therefore, the harmonic analysis of arterial pressure pulse gave abundant information and a great potential to investigate the condition of the whole cardiovascular system. However, there were some limitations for harmonic analysis of the radial pulse wave. The harmonic analysis focused on the fundamental frequency and harmonics of the pulse wave, which had higher resolution at frequencies of 0.8–20 Hz and had a poor resolution at lower frequencies (0.01–0.4 Hz) in this report. The spontaneous fluctuations of arterial blood pressure[62–64] and of peripheral blood pressure[65–67] were correlated with sympathetic and vagal activities at frequencies among 0.01–0.4 Hz. Thus, the harmonic analysis could hardly assess the sympathetic and vagal activities in this case.

5. Conclusion

We demonstrated that black tea could change the status of arterial system and thus change the spectrum of pressure pulse. The impact of black tea on arterial system could be significantly distinguished from that on water control using harmonic analysis of pressure pulse. We proposed that black tea consumption increasing CBF may be one of possible mechanisms in lowering the risk of cognitive impairment and stroke, which was deduced from the results and from the conclusions of previous studies. We also compared the results of this report and previous coffee study, confirming that not only caffeine but also other ingredients in black tea affected the arterial blood pressure and blood pulse spectrum. Therefore, the further investigation is needed to distinguish the effects of caffeine, theanine, catechins, and catechins derivatives on the pulse spectrum.

Furthermore, the harmonic components of pressure pulse could be deemed as vascular kinetic index that described the hemodynamic status in each time frame of the experiment. Thus, the analysis of the harmonic components could effectively help us understand the overall impact of compounds of food or drug on arterial system along the time course of experiment.

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