Observational Study

Medicine®

OPEN

Evaluation of the reduction in central and peripheral arterial blood pressure following an oral glucose load

Shunsuke Murai, MD, PhD[a], Hiroyuki Takase, MD, PhD[b], Tomonori Sugiura, MD, PhD[a,*], Sumiyo Yamashita, MD, PhD[a], Nobuyuki Ohte, MD, PhD[a], Yasuaki Dohi, MD, PhD[c]

Abstract

The clinical significance of measuring central arterial blood pressure has been recently discussed. Although the postprandial reduction in blood pressure is well known, postprandial changes in central blood pressure have not been intensively studied. The present study investigated differences in the reduction of central and peripheral arterial blood pressure after administration of an oral glucose load.

An oral glucose tolerance test (75 g) was performed in 360 participants in our physical checkup program. Brachial and central systolic blood pressures were assessed before and after the glucose load. Central arterial blood pressure was measured noninvasively using an automated device.

The mean age was 53.6 ± 8.2 years. Both brachial (127.9 ± 17.7 to 125.0 ± 16.3 mm Hg) and central arterial blood pressures were significantly decreased after an oral glucose load (118.9 ± 17.9 to 112.8 ± 16.8 mm Hg). The reduction in blood pressure was greater in central (7.3 ± 11.5 mm Hg) than in brachial blood pressure measurements (3.4 ± 11.3 mm Hg, $P < .001$). Extreme blood pressure reduction (>20 mm Hg) was recorded more frequently in central (n = 43, 12.3%) than brachial blood pressure measurements (n = 20, 5.6%).

An oral glucose load decreases both central and brachial systolic blood pressure, with more pronounced effects on central blood pressure. Postprandial reductions in blood perfusion of the important organs such as the brain may be underestimated when postprandial BP reduction is assessed using brachial BP measurements.

Abbreviations: AI = augmentation index, ANOVA = analysis of variance, AUC = area under the curve, BNP = B type natriuretic peptide, BP = blood pressure, OGTT = oral glucose tolerance test.

Keywords: blood pressure, central, hypotension, oral glucose tolerance test, postprandial

1. Introduction

A chronic increase in arterial blood pressure (BP) has been established as a powerful predictor of cardiovascular morbidity and mortality, and blood pressure measured over the brachial artery is routinely used for individual risk evaluation and management of hypertension.[1] However, arterial pressure may vary depending on the site of the BP measurement in the vascular tree. Recent studies have demonstrated that central BP is a superior marker for predicting cardiovascular outcome compared with brachial BP,[2–4] although this assertion remains controversial, suggesting that central BP has a different clinical significance to brachial BP, especially in terms of blood perfusion for vital organs such as brain.

BP reduction after a meal is a well-known physiological hemodynamic change.[5–7] However, severe reduction in postprandial BP may cause unfavorable clinical symptoms such as syncope or falls.[8] Moreover, postprandial hypotension, defined as a systolic BP reduction > 20 mm Hg occurring within 2 hours of a meal,[8,9] has recently been recognized as a risk factor for cardiovascular events.[10,11] Blood pooling within the splanchnic circulation after a meal is proposed to be a main cause of postprandial BP reduction.[12,13] Activation of the sympathetic nervous system in response to this reduced arterial pressure usually increases heart rate, stroke volume and, thereby, cardiac output to prevent a significant reduction in blood pressure, although this has not been intensively studied.[14] The clinical characteristics of BP reduction after a meal may be different in central and peripheral sites. Indeed, central and peripheral BPs differentially respond to various stresses such as physical exercise[15] and pharmacological interventions. The CAFÉ study[16] reported that individuals randomized to atenolol had a 4.3 mm Hg higher central systolic blood pressure than those given amlodipine, despite identical brachial BPs. Further, isotonic exercise increases brachial BP without significant changes in central BP.[17] Thus, the present study was designed to test the

Editor: Erika I. Boesen.

The authors report no conflicts of interest.

[a] Department of Cardio-Renal Medicine and Hypertension, Nagoya City University Graduate School of Medical Sciences, Nagoya, [b] Department of Internal Medicine, Enshu Hospital, Hamamatsu, [c] Department of Internal Medicine, Faculty of Rehabilitation Science, Nagoya Gakuin University, Nagoya, Japan.

[*] Correspondence: Tomonori Sugiura, Department of Cardio-Renal Medicine and Hypertension, Nagoya City University Graduate School of Medical Sciences, 1 Kawasumi, Mizuho-cho, Mizuho-ku, Nagoya 467-8601, Japan (e-mail: tomosugi@med.nagoya-cu.ac.jp).

Medicine (2017) 96:42(e8318)

Received: 14 February 2017 / Received in final form: 25 September 2017 / Accepted: 26 September 2017

http://dx.doi.org/10.1097/MD.0000000000008318

hypothesis that the BP reduction after glucose loading measured at a central site may be different from that measured at a peripheral site.

2. Methods

2.1. Study design and subjects

The present study was designed to evaluate central and brachial BP changes after an oral glucose load. Three hundred sixty subjects aged 20 years or more (n = 360, male = 307; mean age 53.6 ± 8.2 years, range 20–91 years) who underwent a multiphasic health checkup and oral glucose tolerance test (OGTT) in the Department of Health Checkup, Enshu Hospital between August 2014 and November 2015 were enrolled. Subjects with overt cardiovascular disease were excluded from the study. We undertook this study in accordance with the principles of the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of Enshu Hospital. All participants gave written informed consent to participate before the start of the study.

2.2. Study procedures

Our health checkup program included a routine physical examination, chest x-ray, electrocardiography, and laboratory assessment of cardiovascular risk factors. Participants who were prescribed antihypertensive medications were instructed to take medicines in the morning. OGTT and other laboratory tests were performed in the morning after an overnight fast in a room with a controlled temperature (26 ± 2°C). Brachial BP was measured (oscillometric method) and central systolic BP was estimated once by the medical staff after participants were seated in a chair for 5 minutes with their backs supported, and their arms supported at the level of the heart. OGTT was performed with participants consuming 75 g glucose and 200 mL water. Brachial and central BP as well as plasma glucose measurement was performed prior to and 1 and 2 hours after the glucose load. Participants were instructed not to drink water during the OGTT until the sample collection at 2 hours had been completed.

Hypertension was defined by systolic BP ≥140 mm Hg, or diastolic BP ≥90 mm Hg, or if they used antihypertensive medications. Diabetes mellitus was defined by a fasting plasma glucose ≥126 mg/dL or by the use of antidiabetic medications, whereas dyslipidemia was defined by low-density lipoprotein cholesterol ≥140 mg/dL, high-density lipoprotein cholesterol <40 mg/dL, triglycerides ≥150 mg/dL, or the use of antidyslipidemic medications. In some analyses, the response to the glucose load was evaluated by calculating the area under the curve (AUC) in a graph where the plasma glucose level was plotted against time after the glucose load.

2.3. Estimation of central BP

The method of estimating central BP has been described elsewhere.[18] Briefly, radial artery pressure waveforms and brachial BP were recorded simultaneously using a fully automated device (HEM-9000AI; Omron Healthcare, Kyoto). The brachial BP was measured with an oscillometric manometer and the radial pulse waveforms were recorded noninvasively using an applanation tonometer. The radial arterial waveform obtained with this device is reportedly identical to the simultaneously and invasively measured intra-arterial pulse waveform of the opposite radial artery.[18] Inflection points or peaks that corresponded to early and late systolic BP were obtained by multidimensional derivatives of the original pulse pressure waveforms (Fig. 1). The maximal systolic and diastolic pressures in the radial artery were calibrated with the brachial systolic and diastolic BPs, respectively. The late systolic BP in the radial artery (SBP2) was calculated using the following equation:

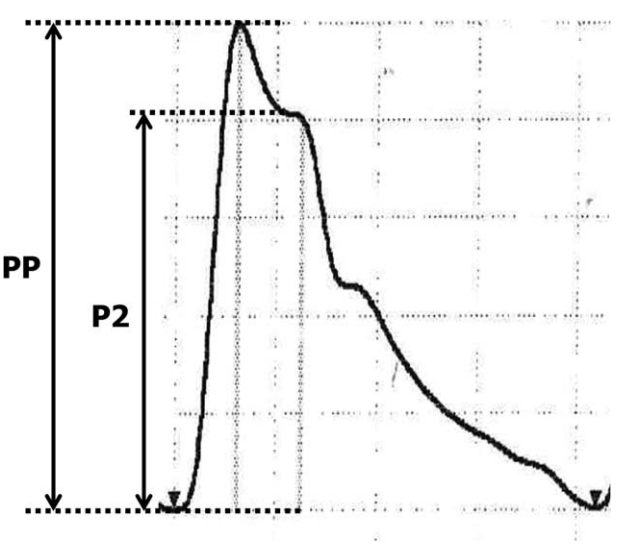

Figure 1. Representative recording of the radial arterial waveform obtained using a fully automated device (HEM-9000AI). PP and P2 indicate the pulse pressure of the radial arterial pressure contour and the height of the late systolic shoulder/peak pressure, respectively.

$$\mathrm{SBP2} = (\mathrm{P2/PP}) \times (\text{systolic BP} - \text{diastolic BP}) + \text{diastolic BP}$$

where P2 and PP indicated the height of the late systolic shoulder/peak pressure and the pulse pressure of the radial arterial pressure contour, respectively. In the present study, SBP2 was recorded as central systolic BP.[19] Subjects who showed any arrhythmia during this procedure were excluded from this study. The augmentation index (AI) of the radial artery was calculated using the following equation:

$$\mathrm{AI}(\%) = (\mathrm{P2/PP}) \times 100.$$

2.4. Biochemical analysis

Serum creatinine, uric acid, total cholesterol, high-density lipoprotein cholesterol, triglycerides, and plasma glucose levels were measured by standard laboratory assays using an automated analyzer (TBA-2000FR; Toshiba Medical Systems Corporation, Tochigi). The low-density lipoprotein cholesterol level was calculated using the Friedewald formula. Hemoglobin levels were determined using an automated analyzer (XE-2100, Sysmex Corporation, Kobe). The B-type natriuretic peptide (BNP) concentration was measured by radioimmunoassay (Shionoria BNP kit, Shionogi, Osaka).

2.5. Statistics

All analyses were performed using IBM SPSS statics 17.0 (Chicago, IL). Data in the text and the tables were expressed as mean ± SD except for BNP. Because the distribution of BNP was skewed to the right, the BNP value was expressed as the median

Table 1

Baseline characteristics of the study participants.

	Total subjects (n = 360)	Female (n = 53)	Male (n = 307)
Age, y	53.6 ± 8.2	50.8 ± 10.7	54.7 ± 7.3*
Body height, cm	163.1 ± 8.8	157.8 ± 5.1	169.6 ± 6.1*
Body weight, kg	58.8 ± 10.5	55.1 ± 10.6	67.0 ± 9.1*
Body mass index, kg/m^2	22.9 ± 3.0	22.1 ± 4.1	23.2 ± 2.7*
Brachial systolic BP, mm Hg	127.9 ± 17.7	113.1 ± 18.2	130.0 ± 16.3*
Brachial diastolic BP, mm Hg	79.9 ± 12.4	70.2 ± 13.2	81.6 ± 11.5*
Heart rate, bpm	69.6 ± 10.7	69.3 ± 10.6	71.0 ± 11.1*
Serum creatinine, mg/dL	0.84 ± 0.16	0.65 ± 0.11	0.88 ± 0.13*
eGFR[a], mL/min/1.73 m^2	74.1 ± 12.3	77.4 ± 15.9	72.7 ± 10.9
Uric acid, mg/dL	5.8 ± 1.3	4.4 ± 0.8	6.1 ± 1.2*
Fasting plasma glucose, mg/dL	98.6 ± 11.1	92.6 ± 8.9	99.9 ± 11.0*
LDL-cholesterol, mg/dL	130.4 ± 28.5	127.5 ± 26.4	129.5 ± 28.5
HDL-cholesterol, mg/dL	62.9 ± 17.1	76.3 ± 17.5	59.8 ± 15.9*
Triglycerides, mg/dL	123.5 ± 132.7	80.7 ± 46.2	133.1 ± 130.3*
Hemoglobin, g/dL	14.7 ± 1.4	12.9 ± 1.4	15.1 ± 1.0*
BNP, ng/L	27 (17–49)	39 (23–54)	44 (15–47)
Risk factors			
Hypertension, %	25.3	11.3	27.7*
Dyslipidemia, %	54.4	32.0	58.3*
Diabetes mellitus, %	3.9	1.9	4.2*
Current smoking habit, %	31.9	7.5	36.1*

Data except for BNP are expressed as mean value ± standard deviation, and BNP is expressed as median [interquartile range].

*$P < .001$ versus female.

BNP = B-type natriuretic peptide, BP = blood pressure, eGFR = estimated glomerular filtration rate, HDL = high-density lipoprotein, LDL = low-density lipoprotein.

[a] The Japanese Society of Nephrology formula.[20]

value (interquartile range) and natural logarithm-transformed prior to statistical analysis. Differences between 2 means that had a normal distribution were compared using unpaired Student *t* tests. Changes in variables following the glucose load were tested for significance by analysis of variance (ANOVA) for repeated measurements followed by Tukey post hoc test. Differences in the response to the glucose load in the brachial and central BP measurements were assessed using 2-way ANOVA. Multiple linear regression analysis was used to evaluate possible determinants for the change in blood pressure following the glucose load. A *P* value of $<.05$ was considered statistically significant.

3. Results

Table 1 lists the baseline characteristics for all subjects. Among the subjects with hypertension, dyslipidemia, and diabetes mellitus, 80.2%, 18.9%, and 21.4% were prescribed with medication, respectively. Most variables in Table 1 were different between female and male subjects and, therefore, male gender was included as a factor in all multivariate models in the present study.

Glucose load increased plasma glucose and plasma insulin concentrations with a peak at 1 hour after the load (Table 2). Brachial BP was decreased 1 hour after the glucose load, with this effect sustained for another 1 hour (Table 2). An apparently similar response was observed in central systolic BP (Table 2). The magnitude of BP reduction was greater in the central than the brachial site ($P < .001$, Fig. 2A), even though the baseline BP measurement was lower when measured at a central site as compared with the brachial site ($P < .001$, Table 2). Indeed, relative BP reduction was 2.7-fold greater in central (4.8%) as opposed to brachial BP (1.8%; paired *t* test, $P < .001$). The differences in the BP reduction between the central and the brachial sites was 3.9 (95% confidence interval, 3.5–4.4) mm Hg (3.2% [2.8–3.5]) 1 hour after the glucose load and 4.0 (3.5–4.5) mm Hg (3.2% [2.8–3.6]) 2 hours after the load. Brachial BP

Table 2

Effects of oral glucose load (75 g) on arterial blood pressure indices.

	Baseline	After 1 h	After 2 h	*P* for trend[a]
Plasma glucose, mg/dL	99.7 ± 13.5	167.9 ± 50.6*†	127.7 ± 38.8*†	<.001
Serum insulin, mg/dL	7.16 ± 4.2	68.7 ± 46.0*†	49.2 ± 38.5*†	<.001
Brachial systolic BP, mm Hg	127.9 ± 17.7	125.1 ± 16.5*	125.0 ± 16.3*	<.001
Brachial diastolic BP, mm Hg	79.9 ± 12.4	75.9 ± 11.9*	76.1 ± 12.1*	<.001
Central systolic BP, mm Hg	118.9 ± 17.9	113.1 ± 16.8*	112.8 ± 16.8*	.003
Augmentation index, %	82.1 ± 12.9	75.8 ± 12.7*	75.4 ± 12.7*	<.001
Heart rate, bpm	69.6 ± 10.7	69.8 ± 9.8	69.1 ± 9.6	.073

Values are mean ± SD.

*$P < .001$ versus baseline, †$P < .001$ versus "after 1 hour" or "after 2 hours".

BP = blood pressure.

[a] Analysis of variance (repeated measurement) followed by Tukey test.

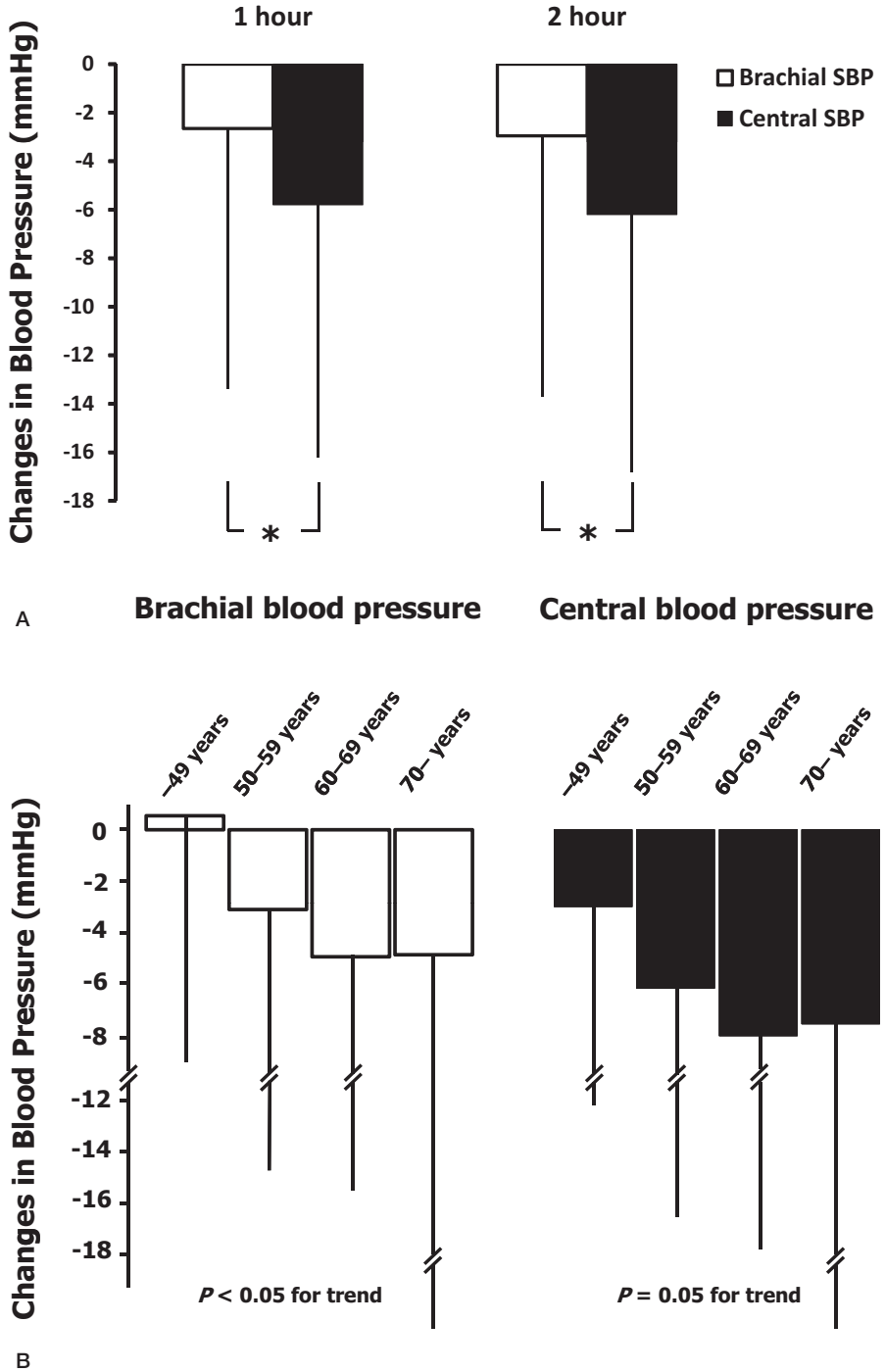

Figure 2. (A) Changes in brachial (open column) and central systolic blood pressure (closed column) 1 and 2 hours following an oral glucose load (75 g). Vertical bars indicate standard deviations. *$P < .001$ by unpaired t test. (B) Changes in brachial (left column) and central systolic blood pressure (right column) 1 hour following an oral glucose load (75 g) in the subgroups of participants aged <50, 50 to 59, 60 to 69, and 70 years or more. Vertical bars indicate standard deviations (standard deviation in participants aged 70 years or more, 17.7 mm Hg for brachial blood pressure and 16.7 mm Hg for central blood pressure). Brachial blood pressure reduction in participants aged <50 years was smaller than that in those aged 50 to 59 years ($P < .05$ by Tukey post hoc test).

reduction >20 mm Hg after the glucose load was evident in 20 subjects (5.6%), whereas 40 subjects (11.1%) showed central BP reduction >20 mm Hg. The augmentation index (AI) was also significantly decreased after the glucose load (Table 2). Changes in these parameters were assessed using data obtained 1 hour after the glucose load, as the changes in variables approached their maximum level at the 1 hour time point.

To determine the factors affecting the BP reduction after the glucose load, univariate and multivariate regression analyses were performed (Tables 3 and 4). In univariate analysis, the reduction in brachial BP was correlated with age, baseline brachial SBP, baseline AI, changes in heart rate, and AUC for the plasma glucose measurement (Table 3). In subanalysis, where participants were divided into 4 groups according to their age,

Table 3

Factors correlated with brachial blood pressure reduction after an oral glucose load.

	Univariate analysis		Multivariate analysis*	
	r	*P* value	β	*P* value
Age, y	0.17	<.001	0.03	.57
Male gender	0.03	.64	−0.13	.02
Body height, cm	−0.02	.70	—	—
BMI, kg/m^2	0.06	.38	—	—
Brachial systolic BP, mm Hg	0.17	<.001	0.44	<.001
Heart rate, bpm	−0.08	.22	−0.09	.13
Serum creatinine, mg/dL	0.02	.74	—	—
Uric acid, mg/dL	−0.01	.96	—	—
FPG, mg/dL	0.06	.38	—	—
LDL-cholesterol, mg/dL	−0.08	.22	—	—
LnBNP	0.08	.23	—	—
Baseline AI, %	0.14	.01	0.06	.30
Change in heart rate, bpm	0.20	<.001	0.22	<.001
Change in FPG, mg/dL	0.01	.929	—	—
AUC-PG, mghr/dL	0.12	.022	0.034	.494
Change in insulin, mg/dL	0.01	.933	—	—
Medication				
ACE-I/ARB	−0.12	.021	−0.055	.265
Beta blockers	0.01	.804	—	—
Calcium channel blockers	−0.05	.310	—	—
Diuretics	−0.05	.382	—	—
Antidiabetic drugs	−0.06	.264	—	—
Statins	−0.03	.684	—	—

ACE/ARB = angiotensin converting enzyme inhibitors/angiotensin receptor blockers, AI = augmentation index, AUC-PG = area under the curve for plasma glucose levels, BMI = body mass index, BNP = brain natriuretic peptide, BP = blood pressure, FPG = fasting plasma glucose, LDL = low-density lipoprotein.
* Multiple linear regression model included factors which showed *P* value <.20 in univariate analysis and gender.

Table 4

Factors correlated with central blood pressure reduction after an oral glucose load.

	Univariate analysis		Multivariate analysis*	
	r	*P* value	β	*P* value
Age, y	0.09	.09	−0.01	.80
Male gender	0.04	.51	−0.08	.12
Body height, cm	0.01	.95	—	—
BMI, kg/m^2	−0.08	.13	—	—
Central systolic BP, mm Hg	0.40	<.001	0.43	<.001
Heart rate, bpm	−0.16	<.01	−0.04	.38
Serum creatinine, mg/dL	0.04	.48	—	—
Uric acid, mg/dL	0.02	.66	—	—
FPG, mg/dL	0.03	.56	—	—
LDL-cholesterol, mg/dL	−0.07	.19	−0.08	.11
LnBNP	0.01	.94	—	—
Baseline AI, %	0.01	.89	—	—
Change in heart rate, bpm	−0.01	.85		
Change in FPG, mg/dL	−0.02	.65	—	—
AUC-PG, mghr/dL	0.12	.65	—	—
Change in insulin, mg/dL	−0.03	.53	—	—
Medication				
ACE-I/ARB	−0.08	.01	−0.05	.36
Beta blocker	0.01	.88	—	—
Calcium channel blockers	0.02	.66	—	—
Diuretics	0.01	.93	—	—
Antidiabetic drugs	−0.01	.98	—	—
Statin	0.02	.69	—	—

ACE/ARB = angiotensin converting enzyme inhibitors/angiotensin receptor blockers AI = augmentation index, AUC-PG = area under the curve for plasma glucose levels, BMI = body mass index, BNP = brain natriuretic peptide, BP = blood pressure, FPG = fasting plasma glucose, LDL = low-density lipoprotein.
* Multiple linear regression model included factors which showed *P* value <.20 in univariate analysis and gender.

−49 years (n=71), 50 to 59 (n=230), 60 to 69 (n=46), 70 or more years (n=13), brachial BP reduction was increased across all subgroups (Fig. 2B, left panel). Central BP reduction after the glucose load tended to increase with increasing age, but this did not reach statistical significance (Fig. 2B, right panel). In multivariate analysis, the reduction in brachial BP after the glucose load was independently correlated with male gender, baseline brachial SBP, and changes in heart rate (Table 3). In contrast, only baseline central BP showed an independent correlation with the reduction in central BP after the glucose load in multivariate analysis (Table 4). Similar results were obtained by multivariate analyses performed in subgroups of participants of different ages (data not shown).

In the next series of analyses, we focused on the difference in the BP reduction between brachial and central BP measurements (Table 5). In univariate analysis, baseline systolic BP, baseline AI, uric acid, and changes in heart rate showed positive correlation, and age, baseline heart rate, fasting plasma glucose showed negative correlation, with the difference between central and brachial BP reduction. Multivariate analysis indicated that baseline AI and changes in heart rate after the glucose load were the independent predictors of the difference between brachial and central BP reduction after adjustment for the factors listed in Table 4. Similar results were obtained in subgroups of participants of different ages (data not shown).

Table 5

Factors correlated with the differential response between brachial and central blood pressure reduction after an oral glucose load.

	Univariate analysis		Multivariate analysis*	
	r	*P* value	β	*P* value
Age, y	−0.12	.03	0.09	.08
Male gender	0.01	.97	0.07	.24
BMI, kg/m^2	−0.06	.28	—	—
Systolic BP, mm Hg	−0.11	.03	−0.11	.05
Heart rate, bpm	−0.22	<.001	0.04	.51
Baseline AI, %	0.25	<.001	0.22	<.001
Serum creatinine, mg/dL	0.02	.74	—	—
Uric acid, mg/dL	0.14	.01	0.09	.09
FPG, mg/dL	−0.13	.02	−0.06	.28
LDL-cholesterol, mg/dL	−0.01	.80	—	—
LnBNP	−0.10	.05	−0.08	.14
Change in heart rate, bpm	0.38	<.001	0.31	<.001
Change in FPG, mg/dL	−0.01	.95	—	—
AUC-PG	−0.01	.85	—	—
Medication				
ACE-I/ARB	−0.01	.84	—	—
Beta blockers	−0.05	.34	—	—
Calcium channel blockers	−0.01	.91	—	—
Diuretics	−0.03	.56	—	—
Antidiabetic drugs	−0.02	.67		
Statins	−0.06	.25	—	—

ACE/ARB, angiotensin converting enzyme inhibitors/angiotensin receptor blockers, AI = augmentation index, AUC-PG = area under the curve for plasma glucose levels, BMI = body mass index, BNP = brain natriuretic peptide, BP = blood pressure, FPG = fasting plasma glucose, LDL, low-density lipoprotein.
* Multiple linear regression model included factors which showed *P* value <.20 in univariate analysis and gender.

4. Discussion

This study demonstrated that a 75 g oral glucose load reduced both brachial and central BPs, with more prominent effects on central as

opposed to brachial BP. To the best of our knowledge, this is the first study to elucidate the differential response of central and brachial BP after an oral glucose load in the general population. The results suggest that postprandial reduction in blood perfusion in the important organs, such as the brain, is underestimated when assessed using postprandial brachial BP changes.

The reduction in brachial BP which is often observed after a meal was reproduced in this study by an oral glucose load in the laboratory. Although the reduction in brachial BP was small, this remained unchanged for at least 2 hours. Both univariate and multivariate analyses indicated an inverse correlation between brachial BP changes and changes in heart rate after the glucose load. These results suggest that heart rate was increased after the glucose load to counterbalance postprandial BP reduction; however, the mean change in heart rate after the glucose load was too small to be identified as a statistically significant change. This could be because the study included participants who did not show postprandial reductions in brachial BP. Indeed, in a subgroup of participants aged <50 years, brachial BP did not (but central BP did) decrease after the glucose load. In contrast, changes in plasma glucose levels showed no significant correlations with brachial BP reduction after the oral glucose load in multivariate analysis. These results suggest that the extent of BP reduction after the oral glucose load was regulated by compensatory mechanisms such as activation of the sympathetic nervous system, and that increased plasma glucose levels do not have a major effect on hemodynamic changes following this glucose load. In line with this concept, BP reduction was not associated with baseline insulin levels, HOMA-R (homeostasis model assessment of insulin resistance), or changes in serum insulin levels (data not shown). In contrast to the brachial BP reduction, the central BP reduction due to glucose load could not be clearly explained by specific factors, suggesting that the central BP reduction involves complicated and unresolved mechanisms.

Interestingly, the reduction in BP after the glucose load was significantly greater (2.7-fold) in the central as opposed to the brachial site. This finding is of clinical importance, because the blood perfusion to the brain is largely dependent on central, but not brachial, arterial blood pressure. In clinical settings, postprandial BP reduction is usually assessed by measuring brachial BP. However, this method can underestimate the postprandial blood perfusion reduction in the brain (especially in cases where autoregulation of brain perfusion is impaired), and does not help to predict the risk of an unfavorable reduction in the perfusion of the brain after a meal. By univariate analysis the difference between the reduction in brachial and central BPs after the glucose load was positively correlated with age, indicating that the risk of underestimating decreased postprandial brain perfusion could increase with increasing age. In addition, the significance of age for predicting the differential response between brachial and central BP disappeared after adjusting for baseline AI, suggesting that an increase in vascular stiffness contributed to an increase in the difference between postprandial central and brachial BP reduction. Unfortunately, the present study did not elucidate possible factors promoting central BP reduction after the glucose load and, thus did not reveal a method for preventing central BP reduction. Although increased arterial stiffness can lead to an increase in central BP, radial AI did not predict postprandial reductions in central BP in the present study, and various complex factors could affect the mechanisms underlying reductions in central arterial BP. Central BP is also closely related to left ventricular load, and central BP rather than brachial BP is suitable for the assessment of cardiac load.[15,21] Thus, postprandial changes in left ventricular load might affect hemodynamics, and this effect cannot be appropriately assessed by the measurement of brachial BP.

This study was conducted to test the hypothesis that arterial BP reduction after a glucose load differs when measured at central and brachial sites, however mechanisms accounting for the greater reduction in central compared with brachial BP are currently unknown. Nevertheless, several possible mechanisms can be proposed. Postprandial BP reduction is mainly caused by a blood volume shift from the central to the splanchnic blood pools as a result of vasodilatation due to the release of gastrointestinal hormones.[22–24] Hence, the reduction in preload may have greater depressor effects on the central rather than the peripheral BP, although there are no previous studies providing evidence for this possibility. Alternatively, vascular wall relaxation after the glucose load may have reduced the amplitude and velocity of the reflection wave, leading to the more prominent arterial BP reduction observed in the central compared with peripheral site. Consistent with this, the augmentation index was decreased after the oral glucose load.

One of the complexities in this study was that some of our subjects had diseases related to life style including hypertension, dyslipidemia, and diabetes mellitus. However, the prevalence of such diseases was quite similar to that observed in the general population, suggesting the results obtained in the present study may be typical of those in the general population. A number of potential mechanisms account for the reduction in BP after a meal; it is not only glucose that provokes BP reduction, but also fructose, xylose, protein, and fat. However, among the various components of the diet, glucose has a relatively strong BP-reducing effect.[25,26] To quantitatively evaluate the arterial BP response after food intake, an oral glucose load of 75 g was used in this study to induce postprandial BP reduction. Although an oral glucose load does not completely mimic the daily food intake in terms of BP response, the protocol used can, at least partially, assess the differential response of central and brachial arterial BP after a meal.

The interpretation of the present results was limited by the lack of a control group, making it possible that water consumption and/or time-dependent changes in BP affected the results. It also should be noted that the 75 g oral glucose load does not have a direct corollary to a mix meal. Another limitation was the small proportion of female subjects (15%) that could have biased the results. Furthermore, an effect of prescribed medications or smoking habits on the present results cannot be completely excluded.

In conclusion, a 75 g oral glucose load reduced both brachial and central arterial BPs, with more prominent effects in central as compared with brachial BP. This suggests that postprandial reductions in perfusion of the important organs such as the brain, is underestimated when postprandial BP reduction is assessed using brachial BP measurements.

References

[1] Turnbull F, Neal B, Algert C, et al. Effects of different blood pressure-lowering regimens on major cardiovascular events in individuals with and without diabetes mellitus: results of prospectively designed overviews of randomized trials. Arch Intern Med 2005;165:1410–9.

[2] Boutouyrie P, Bussy C, Lacolley P, et al. Association between local pulse pressure, mean blood pressure, and large-artery remodeling. Circulation 1999;100:1387–93.

[3] Sharman JE, Fang ZY, Haluska B, et al. Left ventricular mass in patients with type 2 diabetes is independently associated with central but not peripheral pulse pressure. Diabetes Care 2005;28:937–9.

[4] Subherwal S, de las Fuentes L, Waggoner AD, et al. Central aortic pressure is independently associated with diastolic function. Am Heart J 2010;159:1081–8.
[5] Westenend M, Lenders JW, Thien T. The course of blood pressure after a meal: a difference between young and elderly subjects. J Hypertension 1985;3(suppl):S417–9.
[6] Lipsitz LA, Fullerton KJ. Postprandial blood pressure reduction in healthy elderly. J Am Geriatr Soc 1986;34:267–70.
[7] Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope. Clin Geriatr Med 2002;18:141–58.
[8] Van Orshoven NP, Jansen PA, Oudejans I, et al. Postprandial hypotension in clinical geriatric patients and healthy elderly: prevalence related to patient selection and diagnostic criteria. J Aging Res 2010;2010: 243752.
[9] Jansen RW, Lipsitz LA. Postprandial hypotension: epidemiology, pathophysiology, and clinical management. Ann Intern Med 1995;122: 286–95.
[10] Aronow WS, Ahn C. Association of postprandial hypotension with incidence of falls, syncope, coronary events, stroke, and total mortality at 29-month follow-up in 499 older nursing home residents. J Am Geriatr Soc 1997;45:1051–3.
[11] Tabara Y, Okada Y, Uetani E, et al. Postprandial hypotension as a risk marker for asymptomatic lacunar infarction. J Hypertens 2014;32: 1084–90.
[12] Fagan TC, Sawyer PR, Gourley LA, et al. Postprandial alterations in hemodynamics and blood pressure in normal subjects. Am J Cardiol 1986;58:636–41.
[13] Kooner JS, Raimbach S, Watson L, et al. Relationship between splanchnic vasodilation and postprandial hypotension in patients with primary autonomic failure. J Hypertens 1989;7(suppl):S40–1.
[14] De Mey C, Enterling D, Meineke I. Cardiovascular effects of eating, atenolol and their interaction: beta1-adrenergic modulation does not play a predominant role in the genesis of postprandial effects. Br J Clin Pharmacol 1993;36:427–35.
[15] Tanaka S, Sugiura T, Yamashita S, et al. Differential response of central blood pressure to isometric and isotonic exercises. Sci Rep 2014;4:5439.
[16] Williams B, Lacy PS, Thom SM, et al. Differential impact of blood pressure-lowering drugs on central aortic pressure and clinical outcomes: principal results of the Conduit Artery Function Evaluation (CAFE) study. Circulation 2006;113:1213–25.
[17] Dahlöf B, Sever PS, Poulter NR, et al. ASCOT Investigators Prevention of cardiovascular events with an antihypertensive regimen of amlodipine adding perindopril as required versus atenolol adding bendroflumethiazide as required, in the Anglo-Scandinavian Cardiac Outcomes Trial-Blood Pressure Lowering Arm (ASCOT-BPLA): a multicentre randomised controlled trial. Lancet 2005;366:895–906.
[18] Takazawa K, Kobayashi H, Shindo N, et al. Relationship between radial and central arterial pulse wave and evaluation of central aortic pressure using the radial arterial pulse wave. Hypertens Res 2007;30:219–28.
[19] Takazawa K, Kobayashi H, Kojima I, et al. Estimation of central aortic systolic pressure using late systolic inflection of radial artery pulse and its application to vasodilator therapy. J Hypertens 2012;30:908–16.
[20] Matsuo S, Imai E, Horio M, et al. Revised equations for estimated GFR from serum creatinine in Japan. Am J Kidney Dis 2009;53:982–92.
[21] Yamashita S, Dohi Y, Takase H, et al. Central blood pressure reflects left ventricular load, while brachial blood pressure reflects arterial damage. Blood Press 2014;23:356–62.
[22] Jansen RW, Connelly CM, Kelley-Gagnon MM, et al. Postprandial hypotension in elderly patients with unexplained syncope. Arch Intern Med 1995;155:945–52.
[23] Shibao C, Okamoto L, Biaggioni I. Pharmacotherapy of autonomic failure. Pharmacol Ther 2012;134:279–86.
[24] Takase H, Dohi Y, Kimura G. Distribution of central blood pressure values estimated by Omron HEM-9000AI in the Japanese general population. Hypertens Res 2013;36:50–7.
[25] Gentilcore D, Hausken T, Meyer JH, et al. Effects of intraduodenal glucose, fat, and protein on blood pressure, heart rate, and splanchnic blood flow in healthy older subjects. Am J Clin Nutr 2008;87:156–61.
[26] Vloet LC, Mehagnoul-Schipper DJ, Hoefnagels WH, et al. The influence of low-, normal-, and high-carbohydrate meals on blood pressure in elderly patients with postprandial hypotension. J Gerontol A Biol Sci Med 2001;56:M744–8.