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Comparison of carotid-femoral and brachial-ankle pulse wave velocity in association with carotid plaque in a Chinese community-based population

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Abstract

Pulse wave velocity (PWV) is the most widely used measurement of arterial stiffness in clinical practice. This study aimed to evaluate and compare the relationships between carotid-femoral pulse wave velocity (cfPWV) and brachial-ankle PWV (baPWV) and the presence of carotid plaque. This study was designed cross-sectionally and included 6027 participants from a community-based cohort in Beijing. Logistic regression analyses were performed to evaluate and compare the associations of cfPWV and baPWV with the presence of carotid plaque. The mean (SD) cfPWV and baPWV were 8.55 ± 1.83 and 16.79 ± 3.36, respectively. The prevalence of carotid plaque was 45.26% ($n = 2728$). Both cfPWV (per 1 m/s increase: OR = 1.11, 95% CI: 1.07–1.16) and baPWV (OR = 1.04, 95% CI: 1.02–1.06) were independently associated with carotid plaque after adjusting for various confounders. Compared with bottom quartile (cfPWV $\leq$7.31 m/s and baPWV $\leq$14.44 m/s), the top quartile of cfPWV and baPWV had a significantly higher prevalence of carotid plaque (for cfPWV: OR = 1.59, 95% CI: 1.32–1.92; for baPWV: OR = 1.53, 95% CI: 1.26–1.86). However, the relationship of baPWV and carotid plaque was nonlinear, with a positive trend only when baPWV < 16.85 m/s. When comparing relationships between PWV indices and carotid plaque in one model, both cfPWV and baPWV were significantly associated with carotid plaque in participants with baPWV < 16.85 m/s; however, only cfPWV was independently associated with carotid plaque in participants with baPWV $\geq$16.85 m/s. Both cfPWV and baPWV were significantly associated with carotid plaque in the Chinese community-based population. Furthermore, cfPWV was more strongly correlated with carotid plaque than baPWV in participants with baseline baPWV $\geq$16.85 m/s.

KEYWORDS
brachial-ankle pulse wave velocity, carotid plaque, carotid-femoral pulse wave velocity

1 | INTRODUCTION

Pulse wave velocity (PWV), the most widely used measurement of arterial stiffness, is known to be a risk factor for the incidence of cardiovascular disease (CVD).[1–3] In particular, carotid-femoral pulse wave velocity (cfPWV) is recommended as the gold standard for measuring arterial stiffness in clinical practice.[4,5] Brachial-ankle pulse wave velocity (baPWV), another PWV index, can be measured automatically and noninvasively by using an oscillometry-based device[6,7] and has been reported to be closely correlated with cfPWV.[8] Many clinical studies and meta-analyses have shown that both PWV indices are associated with an increased risk of cardio-cerebrovascular diseases or all-cause mortality in different individuals, such as coronary disease patients with a high risk of CVD,[9,10] the general population,[11–14] community-based residents,[15] and elderly individuals.[16–18] However, the comparative associations between both indices of PWV are not clear,[8] and no agreement was reached on which PWV index is more strongly related to cardiovascular outcomes and target organ damage.

Carotid atherosclerosis phenotypes, including carotid intima media thickness and carotid plaques, are associated with vascular pathologies and can be examined by noninvasive imaging technologies, such as carotid artery ultrasound.[19,20] Furthermore, the presence and number of carotid plaques were proven to be associated with clinical cardiovascular events[9,10,21–23] and superior to other reliable surrogate markers.[24,25]

Therefore, this study was designed to assess and compare the relationships between different PWV indices (cfPWV and baPWV) and the presence of carotid plaque in a Chinese community-based population.

2 | MATERIALS AND METHODS

2.1 | Study population

Data for this study were taken from an atherosclerosis cohort, which was established in two communities of Shijingshan District of Beijing, China. A detailed description of the study procedures has already been disclosed.[26] Initially, a total of 9540 participants (≥40 years old) were enrolled in the baseline survey from December 2011 to April 2012, and followed up from September to December 2018. This study was designed cross-sectionally and enrolled participants ($n = 6568$) in the follow-up. We further excluded those without carotid ultrasonography ($n = 21$) and those with ankle brachial index (ABI) ≤.90 or a history of peripheral vascular disease ($n = 520$) due to the possible influence on PWV measurement. Thus, a total of 6027 participants were ultimately included in our analysis. Ethics committee approval was obtained from Peking University First Hospital for all study procedures. We obtained written informed consent from all participants.

2.2 | Data collection

In the study, all participants were interviewed by trained researchers using a standard questionnaire, which was used for the collection of demographic characteristics, lifestyle, medical histories and medications. The term "current smoking" means smoking one cigarette a day for at least 6 months. The term "current drinking" means consuming alcohol once every week for at least 6 months. Weight divided by height squared was used to calculate the patient's body mass index (BMI) [BMI = weight (kg)/height (m^2)]. Peripheral blood pressure (BP) was measured using an Omron HEM-7130 electronic sphygmomanometer (Kyoto, Japan) with the standard protocol, and the final analysis employed the mean value of three consecutive readings.

Venous blood samples were obtained from participants after overnight fasting. The biological markers, which included total cholesterol (TC), triglycerides (TGs), low density lipoprotein cholesterol (LDL-C), high density lipoprotein cholesterol (HDL-C), fasting blood glucose (FBG), and a 2-h oral glucose tolerance test (OGTT), were measured using a Hitachi 7180 Automatic Analyzer (Tokyo, Japan). Enzymatic measurement of plasma serum creatinine (Scr, mol/L) was performed. The Chronic Kidney Disease Epidemiology Collaboration's algorithm was used to get the estimated glomerular filtration rate (eGFR).[27]

A self-reported history of hypertension, taking antihypertensive drugs, systolic BP (SBP) more than 140 mm Hg, and/or diastolic BP (DBP) less than 90 mm Hg were all defined as hypertension. A self-reported history of diabetes, use of hypoglycemic drugs, FBG ≥7.0 mmol/L, and/or OGTT ≥11.1 mmol/L were all defined as diabetes mellitus. A self-reported history of dyslipidemia, any lipid parameter abnormality (LDL-C ≥3.37 mmol/L, TG ≥1.70 mmol/L, TC ≥5.18 mmol/L, and/or HDL-C < 1.04 mmol/L), and/or the use of lipid-lowering drugs were all defined as dyslipidemia. A self-reported history of transient ischemic attack, stroke, or coronary heart disease was used to define cardiovascular disease.

2.3 | Carotid ultrasonography

Carotid ultrasonography was performed on all individuals by trained sonographers using the high-resolution Terason EchoTM ultrasound system (Burlington, MA, USA) with standard scanning and reading protocols. The term "carotid plaque" was used to describe focal structures that encroach into the arterial lumen by more than .5 millimeters (mm) or increase by 50% of the surrounding carotid intima-media thickness value, or that demonstrate a thickness greater than 1.5 millimeters as measured from the intima-lumen interface to the media-adventitia interface at the bilateral common carotid artery (CCA), internal carotid artery, and/or bifurcation.[28]

2.4 | BaPWV and cfPWV measurements

BaPWV and cfPWV were measured for all participants after ≥5 min of rest in an examination room with quiet and temperature control. We used the BP-203RPE III device (Colin-Omron, Tokyo, Japan) to measure baPWV.[29,30] The participant was placed in the supine position, the brachial and tibial artery pulse waveforms were monitored by trained research staff at cuffs wrapped around both ankles and upper arms, and the baPWV value was automatically generated. The higher baPWV of both the left and right sides was used for subsequent analyses after examination.

CfPWV was measured by trained technicians following standard operating procedures using the PulsePen (DiaTecne, Italy) device. The "foot-to-foot" velocity approach was used to determine the time by measuring the pulse waveforms of the carotid and femoral arteries at the location of the strongest pulsations.[31] The distances of the carotid and femoral artery, carotid and sternal angle, and sternal angle and femoral artery were measured. The cfPWV value was computed using the formula [PWV = distance (m)/time (s)] and was at least twice measured. If the difference between the two results exceeded .5 m/s, a third measurement was taken. The average value was then applied.

2.5 | Statistical analysis

We classified the participants into two groups based on their carotid plaque status. For continuous variables, data are expressed as the mean ± standard deviation (SD) or median (interquartile range), and for categorical variables, as a number (percentage). The differences between the two groups were compared using the t test or Kruskal-Wallis rank test for continuous variables as appropriate, and the chi-square test or Fisher exact test for categorical variables as appropriate. The association between PWV indices and carotid plaque was evaluated using a generalized additive model with spline smoothing function, and then piecewise linear regression was utilized to identify the turning points that provided the greatest model likelihood.[32] Univariate and multivariate logistic regression models were established to investigate the associations of cfPWV and baPWV with carotid plaque. Covariables included age, sex, BMI, SBP, DBP, current smoking, current drinking, eGFR, TG, LDL-C, HDL-C, FBG, antihypertensive, hypoglycemic, lipid-lowering drugs, and cardiovascular disease. To compare the associations between different PWV indices and carotid plaque, two PWV indices were forced into the model simultaneously. All statistical analyses were performed using Empower Stats (R, version 2.0) and the package R (version 3.5.1). A two-sided p-value < .05 was considered statistically significant for all tests.

3 | RESULTS

3.1 | Baseline characteristics

Table 1 shows the baseline characteristics of eligible participants, Baseline characteristics of all participants are shown in Table 1. Among the 6027 participants, the average (SD) age was 62.32 ± 7.63 years old, 65.85% were female, and 45.26% (n = 2728) had carotid plaque. Participants who had carotid plaque were more likely to smoke and consume alcohol, which was associated with a higher level of BMI, SBP, FBG, baPWV, and cfPWV, as well as higher rates of hypertension, diabetes mellitus, cardiovascular disease, and the use of antihypertensive, hypoglycemic and lipid-lowering drugs, but had lower levels of eGFR, HDL-C, LDL-C, TC, and TG, compared to those without carotid plaque. And we further analyzed the baseline characteristics in participants without lipid-lowering medication for dyslipidemia, the result found that participants with carotid plaque had higher levels of LDL-C with significant statistically as compared to those without carotid plaque (data not shown). All variables were significantly different between the two groups except DBP and dyslipidemia at baseline.

3.2 | Threshold effect analysis of the effect of PWV indices and carotid plaque

Figure 1 shows the relationships between PWV indices (cfPWV and baPWV) and carotid plaque. However, the trend of the effect of baPWV on carotid plaque was nonlinear. We further conducted a threshold effect analysis and found that the cutoff value of baseline baPWV was 16.85 m/s. In the group with baPWV < 16.85 m/s, baPWV was significantly associated with carotid plaque (per 1 m/s increase: odds ratio (OR) = 1.14, 95% confidence interval (CI): 1.09, 1.19). However, the relationship did not exist in those with baPWV ≥16.85 m/s. Piecewise linear regression analysis indicated a significant difference between the two slopes (p < .001) (Table 2). Moreover, the participants with higher baPWV (> 16.85 m/s) had more common risk factors including higher levels of FBG, TG and peripheral blood pressure, and a higher prevalence of hypertension, diabetes mellitus, dyslipidemia and cardiovascular disease history (Table S1 in Supplementary Material) than those with lower baPWV.

### 3.3 | Associations of cfPWV and baPWV with carotid plaque when considered individually

Table 3 shows the associations between cfPWV and baPWV with carotid plaque. PWV indices as continuous variables were positively correlated with carotid plaque, and both relationships remained statistically significant after adjustment for other possible covariates, with an OR (95% CI) of 1.11 (1.07,1.16) per 1 m/s increase in cfPWV and 1.04 (1.02, 1.06) for baPWV. When both PWV indices were classified into quartiles, compared with the bottom quartile (Q1: cfPWV ≤7.31 m/s and baPWV ≤14.44 m/s) groups, the higher quartile (Q2 to Q4) groups of cfPWV and baPWV showed a significantly higher prevalence of carotid plaque (p for trend < .001), and the top quartile (Q4: cfPWV ≥9.43 m/s and baPWV ≥18.62 m/s) groups, cfPWV and baPWV were associated with carotid plaque with ORs (95% CI) of 1.59 (1.32, 1.92) and 1.52 (1.26, 1.85), respectively.

TABLE 1　Baseline characteristics of participants stratified by carotid plaque

Variables	Overall (n = 6027)	Carotid plaque		p value
		Without (n = 3299)	With (n = 2728)	
Age (years)	62.32 ± 7.63	59.99 ± 6.88	65.15 ± 7.54	<.001
Female, n (%)	3969 (65.85%)	2525 (76.54%)	1444 (52.93%)	<.001
BMI (kg/m²)	25.21 ± 3.31	25.11 ± 3.34	25.33 ± 3.27	.003
SBP (mm Hg)	132.93 ± 16.63	130.09 ± 16.15	136.36 ± 16.55	<.001
DBP (mm Hg)	78.98 ± 9.51	79.18 ± 9.34	78.73 ± 9.71	.066
eGFR (mL/min/1.73m²)	93.29 ± 11.45	95.30 ± 10.47	90.85 ± 12.10	<.001
Total cholesterol (mmol/L)	5.33 ± 1.03	5.42 ± .99	5.22 ± 1.06	<.001
Triglycerides (mmol/L)	1.37 (.98–1.93)	1.39 (1.00–1.95)	1.34 (.96–1.91)	.008
HDL-C (mmol/L)	1.50 ± .35	1.52 ± .36	1.47 ± .35	<.001
LDL-C, mmol/L	3.42 ± .97	3.47 ± .93	3.36 ± 1.01	<.001
FBG (mmol/L)	6.15 ± 1.85	5.98 ± 1.68	6.35 ± 2.02	<.001
baPWV (m/s)	16.79 ± 3.36	16.07 ± 3.14	17.67 ± 3.40	<.001
cfPWV (m/s)	8.55 ± 1.83	8.11 ± 1.54	9.08 ± 2.01	<.001
Current smoking, n (%)	831 (13.92%)	303 (9.27%)	528 (19.55%)	<.001
Current drinking, n (%)	625 (10.44%)	220 (6.71%)	405 (14.95%)	<.001
Prevalence of disease				
Hypertension, n (%)	3279 (54.41%)	1516 (45.95%)	1763 (64.63%)	<.001
Diabetes mellitus, n (%)	1729 (28.69%)	775 (23.49%)	954 (34.97%)	<.001
Dyslipidemia, n (%)	4853 (80.52%)	2680 (81.24%)	2173 (79.66%)	.123
Cardiovascular disease, n (%)	898 (14.90%)	328 (9.94%)	570 (20.90%)	<.001
Medication				
Antihypertensive drugs, n (%)	2160 (35.87%)	949 (28.78%)	1210 (44.47%)	<.001
Hypoglycemic drugs, n (%)	975 (16.19%)	388 (11.76%)	587 (21.53%)	<.001
Lipid-lowering drugs, n (%)	1200 (19.95%)	530 (16.09%)	670 (24.61%)	<.001

Notes: Data are expressed as the mean ± standard deviation (SD), medians (interquartile range) or n (%).

Abbreviations: BMI: body mass index, SBP: systolic blood pressure, DBP: diastolic blood pressure, eGFR: estimated glomerular filtration rate, HDL-C: high density lipoprotein cholesterol, LDL-C: low density lipoprotein cholesterol, FBG: fasting blood glucose, cfPWV: carotid-femoral pulse wave velocity. baPWV, brachial-ankle pulse wave velocity.
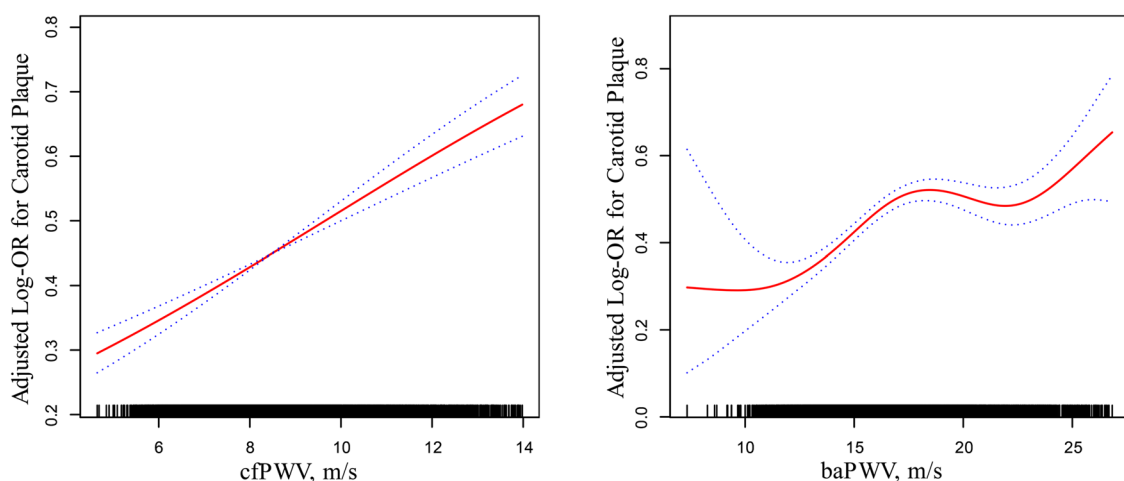
FIGURE 1　Smooth curves of cfPWV and baPWV and carotid plaque*. Note: Both baPWV and cfPWV remove the range of extreme values (± 3SD) on both sides. *Adjusted for age and sex. baPWV, brachial-ankle pulse wave velocity; cfPWV, carotid-femoral pulse wave velocity; OR, odds ratio; SD, standard deviation.

TABLE 2 Piecewise linear regression analysis of baPWV on carotid plaque using model

Model	Result [OR (95%CI)]	p value
Model 1 by standard linear	1.04 (1.02-1.06)	<.001
Model 2 by piecewise linear, turning point: 16.85 m/s		
Slope 1: < 16.85 m/s	1.14 (1.09–1.19)	<0.001
Slope 2: ≥16.85 m/s	.99 (.96–1.02)	.501
Slope 2 - Slope 1	.87 (.82–.92)	<.001
P for log likelihood ratio test		<.001

Adjusted model for age, sex, body mass index, current smoking, current drinking; eGFR, high density lipoprotein cholesterol, low density lipoprotein cholesterol, triglycerides, hypertension, diabetes mellitus, antihypertensive drugs, hypoglycemic drugs, lipid-lowering drugs, and cardiovascular disease.
Abbreviations: baPWV, brachial-ankle pulse wave velocity; OR, odds ratio; CI, confidence interval.

3.4 | Associations of cfPWV and baPWV with carotid plaque when considered simultaneously

Considering the nonlinear relationship between baPWV and carotid plaque, cfPWV and baPWV were put into the model simultaneously by different levels of baPWV. cfPWV was independently associated with carotid plaque regardless of baPWV < 16.85 m/s (for per 1 m/s increase: OR = 1.08, 95% CI: 1.00, 1.17) or ≥16.85 m/s (for per 1 m/s increase: OR = 1.11, 95% CI: 1.05, 1.17). However, the significant

TABLE 4 Associations between cfPWV and baPWV with carotid plaque stratified by baPWV cutoff value when considered simultaneously*

	baPWV < 16.85 m/s		baPWV ≥16.85 m/s	
Variables	OR (95% CI)	P value	OR (95% CI)	P value
cfPWV	1.08 (1.00–1.17)	.043	1.11 (1.05–1.17)	<.001
baPWV	1.10 (1.04–1.17)	.002	.97 (.94–1.01)	.108

*cfPWV and baPWV were added to the model simultaneously. Adjusted for age, sex, body mass index, current smoking, current drinking; eGFR, high density lipoprotein cholesterol, low density lipoprotein cholesterol, triglycerides, hypertension, diabetes mellitus, antihypertensive drugs, hypoglycemic drugs, lipid-lowering drugs, and cardiovascular disease.
Abbreviations: baPWV: brachial-ankle pulse wave velocity, cfPWV: carotid-femoral pulse wave velocity, OR: odds ratio, CI: confidence interval.

relationship between baPWV and carotid plaque remained in only participants with lower baPWV (< 16.85 m/s) (Table 4).

Table 5 displays subgroup analysis. The results showed that among participants with age ≥65 years, BMI ≥24 kg/m², hypertension, diabetes mellitus, and dyslipidemia, cfPWV was more strongly correlated with carotid plaque than baPWV.

4 | DISCUSSION

In the present study, both cfPWV and baPWV were significantly associated with the presence of carotid plaque after adjusting for common risk factors for cardiovascular disease. We found that the association of cfPWV with the presence of carotid plaque was significant

TABLE 3 Regression analysis of the relationships between PWV indices and carotid plaque

PWV Indices	N (%)	Crude model OR (95% CI)	p value	Adjusted model 1 OR (95% CI)	p value	Adjusted model 2 OR (95% CI)	p value
cfPWV (Continuous), per 1 m/s increase		1.39 (1.34–1.43)	<.001	1.17 (1.13–1.21)	<.001	1.11 (1.07–1.16)	<.001
cfPWV Quartiles, m/s							
Q1 (≤7.31)	442 (29.39%)	Ref.		Ref.		Ref.	
Q2 (7.32–8.19)	580 (38.59%)	1.51 (1.30– 1.76)	<.001	1.25 (1.06–1.46)	.007	1.19 (1.00–1.40)	.046
Q3 (8.20–9.42)	746 (49.44%)	2.35 (2.02–2.73)	<.001	1.59 (1.35–1.86)	<.001	1.41 (1.19–1.67)	<.001
Q4 (≥9.43)	960 (63.53%)	4.19 (3.59–4.88)	<.001	1.98 (1.67–2.34)	<.001	1.59 (1.32–1.92)	<.001
P for trend		<.0001		<.0001		<.0001	
baPWV (Continuous), per 1 m/s increase		1.17 (1.15–1.18)	<.001	1.07 (1.05–1.09)	<.001	1.04 (1.02–1.06)	<.001
baPWV Quartiles, m/s							
Q1 (≤14.44)	415 (27.54%)	Ref.		Ref.		Ref.	
Q2 (14.45–16.26)	602 (4.11%)	1.76 (1.51–2.05)	<.001	1.38 (1.17–1.62)	<.001	1.25 (1.06–1.48)	.010
Q3 (16.27–18.61)	801 (53.15%)	2.99 (2.57–3.47)	<.001	1.94 (1.65–2.28)	<.001	1.61 (1.35–1.92)	<.001
Q4 (≥18.62)	910 (6.19%)	3.98 (3.41–4.63)	<.001	1.91 (1.60–2.27)	<.001	1.52 (1.26–1.85)	<.001
P for trend		<.001		<.001		<.001	

Adjusted model 1: adjusted for age and sex. Adjusted model 2: adjusted for age, sex, body mass index, current smoking, current drinking; eGFR, high density lipoprotein cholesterol, low density lipoprotein cholesterol, triglycerides, hypertension, diabetes mellitus, antihypertensive drugs, hypoglycemic drugs, lipid–lowering drugs and cardiovascular disease.
Abbreviations: Ref, reference; baPWV, brachial-ankle pulse wave velocity; cfPWV, carotid-femoral pulse wave velocity; OR, odds ratio; CI, confidence interval.

TABLE 5 Subgroup analyses for the effects of cfPWV and baPWV on carotid plaque when considered simultaneously*

Subgroup	N (%)	cfPWV		baPWV	
		OR (95%CI)	P value	OR (95%CI)	P value
Age, years					
<65	1457 (53.41%)	1.13 (1.06, 1.21)	<.001	1.06 (1.03, 1.10)	<.001
≥65	1271 (46.59%)	1.13 (1.06, 1.20)	<.001	1.01 (.98, 1.05)	.440
Sex					
Male	1284 (47.07%)	1.12 (1.04, 1.21)	.003	.98 (.94, 1.02)	.344
Female	1444 (52.93%)	1.09 (1.03, 1.15)	.004	1.03 (1.00, 1.06)	.049
BMI, kg/m²					
<24	958 (35.12%)	1.12 (1.04, 1.20)	.004	1.02 (.98, 1.06)	.421
≥24	1770 (64.88%)	1.08 (1.02, 1.15)	.006	1.02 (.99, 1.05)	.300
Hypertension					
No	965 (35.37%)	1.09 (1.00, 1.18)	.039	1.05 (1.00, 1.10)	.031
Yes	1763 (64.63%)	1.11 (1.05, 1.17)	<.001	1.00 (.97, 1.03)	.785
Diabetes mellitus					
No	1774 (65.03%)	1.09 (1.03, 1.15)	.004	1.03 (1.00, 1.06)	.096
Yes	954 (34.97%)	1.13 (1.05, 1.22)	.001	.99 (.96, 1.03)	.754
Dyslipidemia					
No	555 (2.34%)	1.05 (.95, 1.16)	.325	1.02 (.97, 1.08)	.450
Yes	2173 (79.66%)	1.10 (1.05, 1.16)	<.001	1.01 (.98, 1.04)	.404

*cfPWV and baPWV were added to the model simultaneously. Adjusted for age, sex, body mass index, current smoking, current drinking; eGFR, high density lipoprotein cholesterol, low density lipoprotein cholesterol, triglycerides, hypertension, diabetes mellitus, antihypertensive drugs, hypoglycemic drugs, lipid-lowering drugs, and cardiovascular disease.

Abbreviations: baPWV, brachial-ankle pulse wave velocity; cfPWV, carotid-femoral pulse wave velocity; OR, odds ratio; CI, confidence interval.

despite the levels of baseline baPWV, while baPWV was not significant associated with carotid plaque in participants with higher levels of baseline baPWV (≥16.85 m/s) in this Chinese community-based population. Furthermore, the correlation of cfPWV with carotid plaque was stronger than baPWV.

Important indicators of early carotid atherosclerosis include stiffening and thickening of the carotid artery.[21,33] Many studies have reported that arterial stiffness and carotid atherosclerosis phenotypes are risk factors for cardiovascular events and unfavorable outcomes in various individuals, including middle-aged[22,34] and elderly participants.[35] Moreover, increased PWV a marker of aortic stiffness, shares the common risk factors with the presence of carotid plaque, which could imply that these two noninvasive examinations are closely correlated as risk factor for cardiovascular disease. However, the relationships between PWV indices and the presence of carotid plaque have not been well established.

Previous cross-sectional studies have indicated that different indices of PWV are associated with carotid atherosclerosis. Joo et al.[22] demonstrated that higher baPWV was significantly associated with a higher prevalence of carotid artery plaque in middle-aged asymptomatic individuals. Tomonori et al.[21] and Zureik et al.[36] similarly, the significant association between baPWV and the existence of carotid plaque was found. Bai et al.[37] found that cfPWV was significantly asso-

ciated with arterial plaque. Our study demonstrated similar results that cfPWC and baPWV were independently associated with the presence of carotid plaque. Our further analysis observed the similar results of relationships between PWV indices and carotid plaque area[38] and increased cIMT.[39]

However, there have been some studies to the contrary. Masugata et al.[40] reported that the association between baPWV and carotid plaque score was not closed (r = .37). In a Japanese healthy population study, Kubozono and colleagues[11] found that carotid atherosclerosis was significantly associated with only high baPWV (> 14 m/s). Inconsistent with our findings, we found that the significant relationships between baPWV and carotid plaque disappeared in participants with higher baPWV (≥16.85 m/s). Another study observed a similar result to our findings that no significant relationship between baPWV and carotid plaque formation was found in patients with higher baPWV (≥14 m/s).[41] We observed the non-linearity relationship between baPWV and carotid plaque in a generalized additive model with the spline smoothing function and identified the threshold using piecewise linear regression analysis. Subgroup analysis demonstrated that baPWV was not significantly associated with carotid plaque in individuals with pre-existing cardiovascular risk factors, that along with higher baPWV, which may help to explain the relationship between baPWV and carotid plaque disappeared in participants with baPWV ≥16.85 m/s.

Noticeably, to the best of our knowledge, only a few studies have focused on the comparative assessment of the effects of cfPWV and baPWV on carotid atherosclerosis, especially in the Chinese population. A study demonstrated that the correlation between baPWV and all parameters of left ventricular structure and arterial function was stronger than that of cfPWV in a population of 320 Taiwanese.[42] In another Northern Shanghai Study with 1599 elderly patients aged over 65 years, Lu et al. found that only cfPWV was significantly associated with carotid IMT when two PWV indicies were put into the model simultaneously.[35] Similarly, our study found that cfPWV, but not baPWV, was associated with carotid plaque in participants with baPWV ≥16.85 m/s when putting two PWV indices into the model simultaneously. cfPWV has shown a better correlation with carotid plaque than baPWV in elder participants from subgroup analysis. Meanwhile, similar results appeared in those participants with obesity, hypertension, diabetes, or dyslipidemia, which might indicate that cfPWV should be considered than baPWV as a marker of carotid plaque in individuals with pre-existing cardiovascular risk factors. Furthermore, the stronger correlation between cfPWV with carotid plaque than baPWV in our study was not surprising. The carotid artery is one of the elastic arteries, along with muscular arteries and arterioles, that are composed of the arterial system. BaPWV covers both central large artery and large portion of peripheral medial size artery (muscular artery), whereas cfPWV covers the central large artery, mostly the aorta (elastic arteries).[1,7] Therefore, cfPWV may be more sensitive to elastic arterial stiffness than baPWV.

Additionally, several possible mechanisms linking increased PWV and carotid plaque should be discussed. Increased aortic stiffness leads to increased peripheral blood pressure and promote vascular remodeling,[43] Increased pulse pressure[44] and luminal pressure[45] may also be associated with development of plaque and accelerate plaque formation. Moreover, the mechanisms of atherosclerotic plaque should also take into consideration endothelial dysfunction and oxidative stress.[46,47]

Several limitations need to be addressed in our study. First, this is a cross-sectional study, and the direct causality between PWV indices and the risk of future carotid atherosclerotic events cannot be determined. Future cohort studies are needed. Second, all participants were from a Chinese community-based cohort, and external generalizability is limited. Third, there is a nonlinear relationship between the effects of baPWV on carotid plaque, which may be explained as baPWV being more susceptible to various disease conditions.[7] Therefore, future longitudinal studies should focus on the causal relationship between different PWV indices and carotid atherosclerosis.

In conclusions, the present study demonstrated that both cfPWV and baPWV were independently associated with the presence of carotid plaque in a Chinese community-based population. The association of cfPWV with carotid plaque was stronger than that of baPWV in participants with baseline baPWV ≥16.85 m/s. Future studies are required to explore and investigate the longitudinal causal effects of arterial stiffness on carotid atherosclerosis progression.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.