

# Higher blood pressure increases arterial stiffness modified by blood glucose levels in a Chinese community-based study

This article was published in the following Dove Press journal:  
*Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*

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**Background:** Increased arterial stiffness measured by brachial-ankle pulse wave velocity is associated with cardiovascular disease. However, the rates at which brachial-ankle pulse wave velocity and blood glucose accelerate within individuals who differ in blood pressure levels are largely unknown.

**Methods:** This study was based on the baseline data of a Chinese community-based atherosclerosis cohort which included 7402 individuals. Using generalized linear regression models, the relationship between blood glucose levels and brachial-ankle pulse wave velocity, and the relationship between blood pressure levels and brachial-ankle pulse wave velocity were examined.

**Results:** A marked interaction between hypertensive state and diabetic state was seen for brachial-ankle pulse wave velocity ( $P$  for interaction  $<0.001$ ). The adjusted coefficient for subjects stratified by hypertensive groups and diabetic states showed that the highest brachial-ankle pulse wave velocity risk subjects were those who had both diabetes and hypertension ( $B=403.24$ ; 95% CI: 372.43–434.05;  $P<0.001$ ).

**Conclusions:** The participants with increased arterial stiffness demonstrate a high prevalence of higher blood pressure. When high blood glucose levels co-occur with high blood pressure levels, there is a remarkable increase in arterial stiffness.

**Keywords:** communities, diabetes, hypertension

## Introduction

Cardiovascular disease remains a major cause of health loss for all regions of the world.<sup>1</sup> And epidemiological studies have demonstrated that increased arterial stiffness<sup>2,3</sup> is an independent risk factor for cardiovascular events. Degenerative stiffness of the arterial beds is referred as arteriosclerosis,<sup>4</sup> which results in cardiovascular events. An independent predictive value of arterial stiffness for cardiovascular events has been demonstrated in general as well as in selected populations. Increased arterial stiffness is also an independent risk factor for multiple organ damage<sup>5</sup> and dementia.<sup>6,7</sup> Arterial stiffness is a shared consequence of diabetes mellitus type 2 (T2DM) and is causally involved in the progression of diabetes complication.<sup>8,9</sup> On the other hand, cross-sectional studies show that blood pressure (BP) is strongly associated with brachial-ankle pulse wave velocity (baPWV). BP is transmitted into the arterial wall, where its increase progressively stimulates the less distensible collagen fibers, thus resulting in a progressively stiffer artery.<sup>10</sup> This process may also lead to aortic root dilation.<sup>11</sup> Therefore, it is important to study arterial stiffness, which can be measured

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by a simple, invasive, and accurate index of brachial-ankle PWV, and it has been clinically validated.<sup>12</sup>

However, the rates at which baPWV and blood glucose accelerate within individuals who differ in blood pressure levels are largely unknown, but their definition is required to unravel the conundrum of interactions of blood glucose levels and blood pressure levels as baPWV increases and is also required to correct power analyses. Therefore, understanding conundrum between blood glucose levels, blood pressure levels, and arterial stiffness is a major public health priority.

To address present gaps in understanding modification of blood glucose levels when the blood pressure level affects arterial stiffness, the relation of a comprehensive panel of blood pressure levels, blood glucose levels was assessed based on the baseline data of a Chinese community-based atherosclerosis cohort.

## Materials and methods

### Study subjects

The study has been conducted from December 2011 to April 2012 at the baseline of a Chinese community-based atherosclerosis cohort. At first, 9540 participants were recruited in Gucheng and Pingguoyuan communities in Shijingshan district of Beijing, China. The participants were recruited either by responding to recruitment posters that detailed the study or by invited phone calls if they had health medical records in community health centers. The study design and selection criteria have been introduced before.<sup>13</sup> To avert the bias from the atherosclerosis or related diseases, the patients with a history of coronary heart disease, stroke/transient ischemic attack, peripheral arterial disease (ankle-brachial index (ABI)<0.9), anemia, chronic kidney disease, and renal artery stenosis were excluded (n=1643). Then, missing data were deleted, which included pulse wave velocity (PWV) (n=331), systolic blood pressure (SBP) or diastolic blood pressure (DBP) (n=97), fasting blood glucose (FBG) (n=1), 2-hr post-load glucose (2-h PG) (n=62), and ABI (n=4). Finally, 7402 eligible participants were involved in our analyses. All of them offered written informed consent. The study protocol was approved by the ethics committee of Peking University First Hospital. The research was conducted according to the World Medical Association Declaration of Helsinki.

### Data collection

The data were collected by trained research staff according to a standard operation procedure. Subjects were interviewed using a standardized questionnaire, including

demographic characteristics, health behavior, histories of drugs and diseases. Current drinking habit was defined as drinking once per week lasting at least half a year. Current smoking habit was defined as current active smokers with one cigarette per day lasting at least half a year. Body mass index (BMI) was calculated as weight (kg)/[height (m)]<sup>2</sup>.

### Blood pressure tests

Seated blood pressure was obtained from the right arm with calibrated sphygmomanometer HEM 7117 device (Omron Healthcare Co Ltd) after the subjects had rested in the seated position for 5 mins in a quiet room. The average was calculated using three consecutive measurements separated by  $\geq 1$  min interval. In light of 2013 ESC-ESH guidelines, participants were classified into three groups: optimal BP, SBP<120 mmHg, and DBP<80 mmHg without antihypertensive treatment; prehypertension, SBP 120–139 mmHg, or DBP 80–89 mmHg without antihypertensive treatment; hypertension, SBP $\geq$ 140 mmHg or DBP $\geq$ 90 mmHg or antihypertensive drug usage.

### Blood glucose tests

Overnight fasting blood samples at least 12 hrs were drawn from the antecubital vein using 4 mL coagulation-promoting vacuum tubes in the morning. Subsequently, the subjects underwent standard 75-g oral glucose tolerance test (or, diabetes mellitus (DM) patients consumed equivalent bread) with 2 hr plasma glucose sampled. Biochemistry index in plasma, including fasting blood glucose, 2-hr post-load glucose, total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and total triglycerides (TG) were examined by the automatic biochemical analyzer (Roche-C8000) according to a standard procedure. In line with the American Diabetes Association diagnostic criteria, participants were classified into three groups: normal glucose, FBG<5.6 mmol/L and 2-h PG <7.8 mmol/L without antidiabetics treatment; prediabetes, FBG 5.6–6.9 mmol/L or 2-h PG 7.8–11.0 mmol/L without antidiabetics treatment; diabetes, FBG $\geq$ 7.0 mmol/L or 2-h PG  $\geq$  11.1 mmol/L or any antidiabetics treatment.

### Brachial-ankle pulse wave velocity

After 5 mins seated rest in a quiet room, the brachial-ankle pulse wave velocity (baPWV) measured from the participants in the supine position was obtained by a noninvasive vascular screening device (BP-203RPE II device, Omron Healthcare, Kyoto, Japan) by trained technician according to standard procedures in the morning. Blood pressure and pulse waves velocity in bilateral brachial tibial arteries

were recorded simultaneously, placing four pneumatic pressure cuff in arms and ankles. The baPWV was the average of left and right baPWV due to the strong correlation between them ( $r=0.968$ ,  $P<0.001$ ).

## Statistical analyses

All data were represented as mean $\pm$ SD for continuous variables and proportion for categorical variables. ANOVA was used to examine intergroup differences of continuous variables. Chi-square test was performed for the comparison of the difference in categorical variables. Generalized linear regression models were applied to assess the association of different blood glucose level and blood pressure level with baPWV. For multiple generalized linear regression models (adjusted models), age, sex, BMI, waist-to-hip ratio (WHR), physical exercise, current drinking, current smoking, TG, TC, high-density lipoprotein cholesterol (HDL), diabetic state, hypertensive

groups, antihypertensive drugs, antidiabetics drugs, lipid-lowering drugs were adjusted in corresponding models. Moreover, the interaction of diabetic state and hypertensive state on baPWV was detected by the generalized linear regression by adding a cross-product term with main effects and other covariates. Then, the joint effects were estimated after adjusting for covariates. The analyses were performed using SAS 9.3 and Empower(R) (www.empowerstats.com, X&Y solutions, Inc., Boston, MA) and R (<http://www.R-project.org>). A two-sided  $P$ -value $<0.05$  was considered statistically significant.

## Results

### Characteristics by different blood pressure level

Characteristics of the study subject by different blood pressure level summarized in Table 1. The mean age of the

**Table 1** Characteristics by different blood pressure level

Variable	Total N=7402	Optimal BP N=1431	Prehypertension N=2697	Hypertension N=3274	P
Age, yr	56.04 $\pm$ 8.63	51.92 $\pm$ 7.36	54.82 $\pm$ 7.75	58.84 $\pm$ 8.87	<0.001
Sex, Male	2659(35.91)	316(22.08)	1000(37.08)	1342(40.99)	<0.001
BMI, kg/m <sup>2</sup>	25.92 $\pm$ 3.37	24.34 $\pm$ 3.09	25.75 $\pm$ 3.22	26.75 $\pm$ 3.34	<0.001
WHR, %	0.90 $\pm$ 0.06	0.87 $\pm$ 0.06	0.90 $\pm$ 0.06	0.91 $\pm$ 0.06	<0.001
Waist, cm	82.40 $\pm$ 8.47	77.87 $\pm$ 7.84	81.95 $\pm$ 8.08	84.75 $\pm$ 8.18	<0.001
Current smoking	1449(19.58)	214(14.95)	597(22.14)	638(19.49)	<0.001
Current drinking	1771(23.93)	251(17.54)	684(25.36)	836(25.53)	<0.001
Physical exercise, $\geq$ 5 days per week	4995(67.48)	856(59.82)	1785(66.18)	2354(71.90)	<0.001
Blood pressure levels					<0.001
Normal glucose	2980(40.26)	835(58.35)	1210(44.86)	935(28.56)	
Prediabetes	2769(37.41)	443(30.96)	1007(37.34)	1319(40.29)	
Diabetes	1653(22.33)	153(10.69)	480(17.80)	1020(31.15)	
TG, mmol/L	1.59 $\pm$ 1.29	1.34 $\pm$ 1.39	1.59 $\pm$ 1.29	1.71 $\pm$ 1.22	<0.001
TC, mmol/L	5.35 $\pm$ 0.99	5.27 $\pm$ 0.96	5.37 $\pm$ 0.99	5.37 $\pm$ 1.01	0.002
HDL, mmol/L	1.44 $\pm$ 0.38	1.55 $\pm$ 0.40	1.44 $\pm$ 0.38	1.40 $\pm$ 0.36	<0.001
Antihypertensive drugs	1972(26.64)	0	0	1972(60.23)	–
Lipid-lowering drugs	495(6.69)	56(3.91)	106(3.93)	333(10.17)	<0.001
Antidiabetes drugs	598(8.08)	65(4.54)	157(5.82)	376(11.48)	–

**Abbreviations:** BMI, body mass index; BP, blood pressure; WHR, waist-to-hip ratio; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein cholesterol.

population was  $56.04 \pm 8.63$  years and 64.09% of them were women. There was 1431 (19.33%) normal BP, 2697 (36.44%) prehypertension, and 3274 (44.23%) hypertension. Age, sex, BMI, WHR, current smoking, current drinking, physical exercise, hypertensive groups, TG, TC, HDL, antihypertensive drugs, and lipid-lowering drugs were statistically different among the three groups ( $P < 0.05$ ).

## The effect of blood pressure levels and blood glucose levels on increased baPWV risk

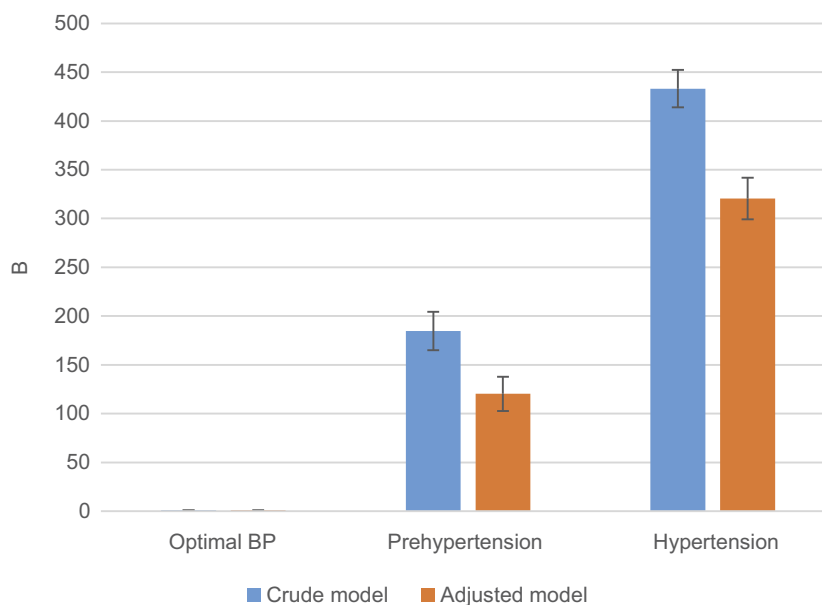
The effect of different blood pressure levels and blood glucose levels on increased baPWV risk from generalized linear regression was presented in Figures 1 and 2. In unadjusted model, both prediabetes and diabetes were significantly associated with an increased risk of baPWV compared with normal glucose ( $P < 0.001$ ). The associations were attenuated after adjustment ( $B = 43.62$ ,  $P < 0.001$ ;  $B = 95.58$ ,  $P < 0.001$ , respectively). Similar to the association with diabetic state and baPWV risk, prehypertension and hypertension were significantly associated with an increased risk of baPWV compared with optimal BP ( $P < 0.001$ ) in unadjusted model, and the aforementioned associations were attenuated after adjustment ( $B = 120.34$ ,  $P < 0.001$ ;  $B = 320.35$ ,  $P < 0.001$ , respectively). (Table S1.)

## The effect of blood glucose levels on the risk of baPWV by different blood pressure level

As shown in the upper half of Figure 3, there was significantly higher baPWV risk in prediabetes and diabetes compared with normal glucose in all blood pressure levels. Prediabetes did not show a significantly higher baPWV risk compared with normal glucose in optimal BP group ( $P = 0.459$ ) after correcting for confounding variables. (Table S2.)

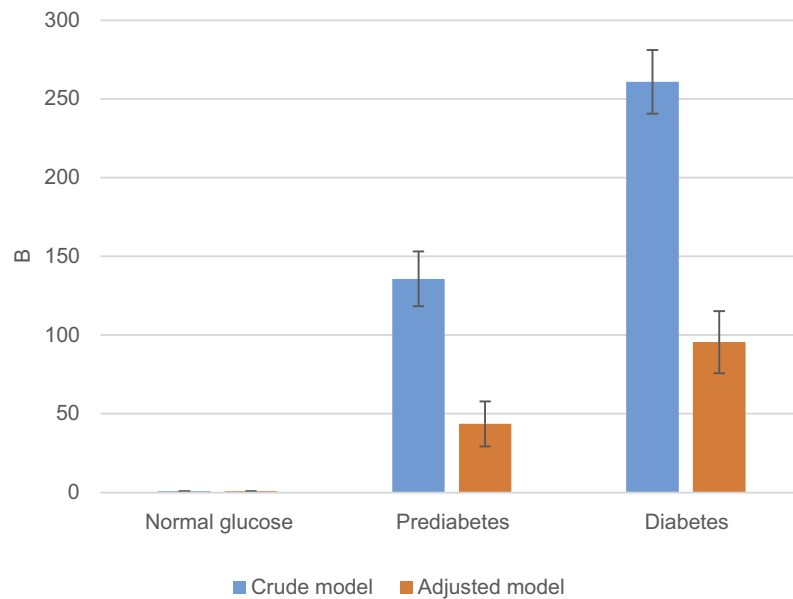
## Interaction of blood glucose levels and blood pressure level on baPWV

For each blood pressure level, there was a high increase in baPWV with prediabetes and diabetes compared with normal glucose (Figures 4 and 5). When the participants were stratified by blood pressure levels (Table S3.), prediabetes did not have significantly higher baPWV risk for optimal BP group ( $P = 0.705$ ). However, a marked interaction between blood pressure levels and blood glucose levels was seen for baPWV (adjusted  $B = 19.71$ ;  $P$  for interaction  $< 0.001$ ). The adjusted coefficient for subjects stratified by categories of blood pressure levels and blood glucose levels (Table S3.) showed that the highest baPWV risk subjects were those who had both diabetes and hypertension (adjusted  $B = 403.24$ ;  $P < 0.001$  compared with optimal BP/normal glucose).



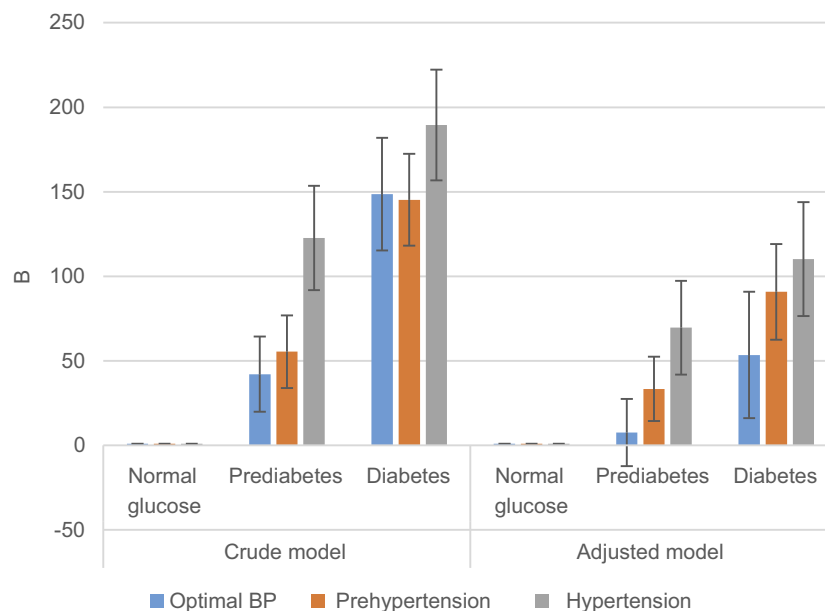
**Figure 1** The effect of blood pressure levels on the risk of baPWV. Adjusted for sex, BMI, WHR, physical exercise, current drinking, current smoking, TG, TC, HDL, antihypertensive drugs, antidiabetes drugs, and lipid-lowering drugs.

**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; WHR, waist-to-hip ratio; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein cholesterol.



**Figure 2** The effect of blood glucose levels on the risk of baPWV. Adjusted for sex, BMI, WHR, physical exercise, current drinking, current smoking, TG, TC, HDL, antihypertensive drugs, antidiabetes drugs, and lipid-lowering drugs.

**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; WHR, waist-to-hip ratio; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein cholesterol.



**Figure 3** The effect of blood glucose levels on the risk of baPWV by different blood pressure level. Adjusted for sex, BMI, WHR, physical exercise, current drinking, current smoking, TG, TC, HDL, antihypertensive drugs, antidiabetes drugs, and lipid-lowering drugs.

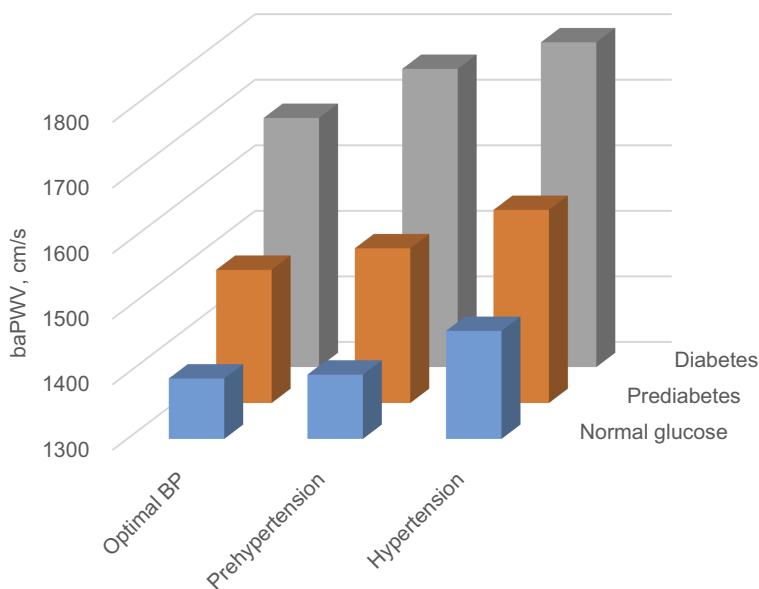
**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; WHR, waist-to-hip ratio; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein cholesterol.

## Discussion

In this study, we not only observe the association between different blood pressure levels and baPWV, different blood glucose levels and baPWV but also find out the modification of blood glucose levels when higher blood pressure level increases baPWV. To our knowledge, this study is first to

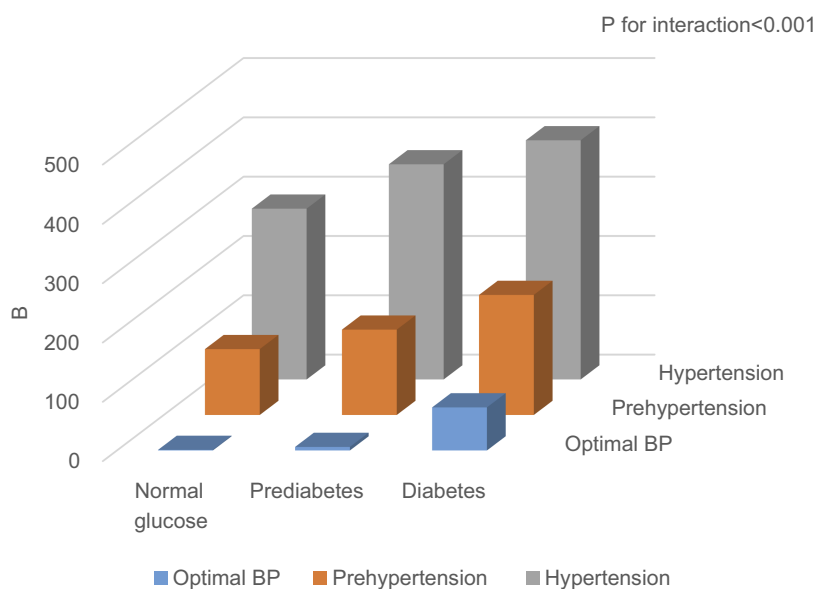
show the adverse and independent impact of high blood glucose on arterial stiffness, particularly in those with the higher blood pressure in Chinese community-based population.

Our study shows both prediabetes and diabetes are significantly associated with an increased risk of baPWV compared with normal glucose ( $P < 0.001$ ). And several previous studies



**Figure 4** Shown are adjusted least squares mean (standard error) for baPWV by diabetic state and hypertensive groups. Adjusted for sex, BMI, WHR, physical exercise, current drinking, current smoking, TG, TC, HDL, antihypertensive drugs, antidiabetes drugs, and lipid-lowering drugs.

**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; WHR, waist-to-hip ratio; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein cholesterol.



**Figure 5** The joint effect and interaction of blood pressure levels, blood glucose levels on baPWV in adjusted models. Adjusted for sex, BMI, WHR, physical exercise, current drinking, current smoking, TG, TC, HDL, antihypertensive drugs, antidiabetes drugs, and lipid-lowering drugs.

**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; WHR, waist-to-hip ratio; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein cholesterol.

have also shown an increase in fasting plasma glucose (FPG), even within the normal range, associated with aggravated arterial stiffness than the normoglycemia.<sup>14–16</sup> Prentner et al indicate that one of the most important components in the onset of diabetes is arterial stiffness, and before the development of overt diabetes, the endothelial dysfunction may even be accompanied by the early insulin resistance and impaired fasting glucose.<sup>8</sup> Another study also finds blunted endothelial

function can lead to increased stiffness of the large arteries.<sup>17</sup> Both endothelial NO dysregulation and advanced glycation end products (AGEs) play huge roles in development of arterial stiffness.<sup>8</sup> Inhibition of NO bioavailability contributes to the increase in BP.<sup>18</sup> AGEs is the production of proteins and lipids on exposure to the setting of hyperglycemia. And it can accelerate the age-related vascular changes and the onset of cardiovascular events in both non-diabetic and diabetic

populations.<sup>19–21</sup> Furthermore, superoxide production increased and NO synthase activation impaired in the insulin-resistant state, leading to a reduction in NO bioavailability. Ultimately it will give rise to arterial stiffness and herald the development of microvascular changes.<sup>22–24</sup>

Another studies release that increased SBP, even in the prehypertension range, relates to the elevated PWV which persisted after adjusting for traditional cardiovascular risk factors.<sup>25,26</sup> Similar to the result of our research: prehypertension and hypertension were significantly associated with an increased risk of baPWV compared with optimal BP ( $P<0.001$ ). There is also a complex relationship between arterial stiffness and blood pressure. Some longitudinal studies indicate that higher SBP is associated with faster increase of PWV,<sup>25</sup> and the results of other reports reveal that higher PWV may herald the longitudinal increase in SBP.<sup>27,28</sup> The association between arterial stiffness and BP could be described as a vicious cycle. Nigam et al suggest the arterial wall structural alterations and mechanical stretch changes maybe the mechanisms of hypertension on aortic stiffening, such as increased collagen content and decreased elastin content.<sup>29</sup> Because of the decrease in arterial compliance, the SBP is increased and the DBP is decreased, which contributes to the increase of the pulse pressure (PP). On the one hand, the vascular remodeling impacts BP.<sup>30</sup> A stiffer wall gives rise to the higher PWV, and then causes the early arrival of reflection pressure waves. The above series of processes lead to the increase in SBP and PP.<sup>31</sup> Circadian BP variability<sup>32</sup> and chronic kidney disease also impact on BP variability.<sup>33</sup> As noted in the Hypertension Branch and Vascular Biology review, the concordance of results in animal and clinical studies strengthens the support for the hypothesis that arterial stiffness plays a potential causal role in the development of hypertension and stresses the need to find molecular pathways that contribute to arterial stiffness and subsequent hypertension.<sup>34</sup>

Epidemiological studies have established that hypertension and DM are independent risk factors for atherosclerosis. However, there are few reports about mechanism of the interaction of blood pressure levels and blood glucose levels on arterial stiffness. Our study releases a marked modification of blood glucose levels when higher blood pressure level increases arterial stiffness ( $P$  for interaction $<0.001$ ). Ma et al indicate that the interaction of hypertension and T2DM aggravates endothelial dysfunction and impairs the smooth muscle function.<sup>35</sup> Tsao et al demonstrate that both hypertension and DM give rise to increased monocyte adherence to the endothelium. Monocyte

chemotactic protein-1 expression and increased vascular superoxide production are associated with the above abnormality. In addition, there may be an additive interaction between hypertension and hyperglycemia in their effects on endothelial adhesiveness.<sup>36</sup> The inflammation increases in arterial stiffness and thickness.<sup>37</sup> Smooth muscle cell proliferation, and deterioration of elastin may also result in arterial wall remodeling.<sup>38</sup>

Relatively large sample size, community-based population, and the first attempt to show the modification of blood glucose levels when higher blood pressure level increases arterial stiffness are strengths of this study. However, several limitations should be noted. The limitation of our analysis is its cross-sectional design. We can only find the correlations between variables by regression analysis. More research is needed to reveal the cause–effect relationship. In our work, to avoid excessive collinearity that may make the models robust, we adjusted for some important confounding factors which could increase the arterial stiffness. But we did not control for the phase of the menstrual cycle in premenopausal women, this causes variations in blood pressure and vascular function. And we did not control for caffeine, alcohol consumption or any unaccustomed physical activity 24-h before each visit. This plays a role in vascular function.

## Conclusion

In conclusion, the participants with increased arterial stiffness demonstrated a high prevalence of higher blood glucose, which was independently associated with baPWV. When blood pressure levels co-occurred with blood glucose levels, there was a remarkable increase in baPWV. The findings in our study raised the possibility of the modification of blood glucose levels when higher blood pressure level increases arterial stiffness that, if confirmed in future studies, may have important public health implications for the prevention of arterial stiffness.

## Abbreviation list

baPWV, brachial-ankle pulse wave velocity; T2DM, diabetes mellitus type 2; BP, blood pressure; ABI, ankle-brachial index; PWV, pulse wave velocity; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; 2-h PG, 2-hr post-load glucose; BMI, Body mass index; DM, diabetes mellitus; TC, total cholesterol; HDL-C/HDL, high-density lipoprotein cholesterol; TG, total triglycerides; WHR, waist-to-hip ratio; AGEs, advanced glycation end products; PP, pulse pressure.

## Ethics approval and consent to participate

The study protocol was approved by the ethics committee of Peking University First Hospital. The research was conducted according to the World Medical Association Declaration of Helsinki. The adolescents who participated in this study agreed in writing to participate and their legal guardians signed an informed consent form.

## Availability of data and materials

The data that support the findings of this study are available from Peking University First Hospital, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Peking University First Hospital.

## Acknowledgments

We really appreciate the staff of Gucheng and Pingguoyuan Community Health Centers and their research coordinators who participated in this survey and thank them for their assistance in data acquisition.

The study was supported by grants from the National Natural Science Foundation of China (81172768, 81872692), Beijing Municipal Natural Science Foundation (7182085) and the UM-PUHSC Joint Institute for Translational and Clinical Research (BMU20110177).

## Author contributions

X Dai wrote the manuscript. Z Liu performed the statistical analyses. D Chen and Y Zhang revised the paper. All authors contributed towards data analysis, drafting and critically revising the paper, gave final approval of the version to be published, and agreed to be accountable for all aspects of the work.

## Disclosure

The authors declare that they have no competing interests in this work.

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## Supplementary materials

**Table S1** The effect of blood pressure levels, blood glucose levels on the risk of baPWV

Variables	Crude model		Adjusted model	
	B(95%CI)	P	B(95%CI)	P
Blood pressure levels				
Optimal BP	Ref		Ref	
Prehypertension	184.65(164.88,204.41)	<0.001	120.34(102.74,137.93)	<0.001
Hypertension	433.01(413.86,452.16)	<0.001	320.35(299.01,341.69)	<0.001
Blood glucose levels				
Normal glucose	Ref		Ref	
Prediabetes	135.72(118.31,153.13)	<0.001	43.62(29.33,57.90)	<0.001
Diabetes	260.78(240.55,281.01)	<0.001	95.58(75.85,115.32)	<0.001

**Abbreviation:** baPWV, brachial-ankle pulse wave velocity.

**Table S2** The effect of blood glucose levels on the risk of baPWV by different blood pressure level

Blood glucose levels	Optimal BP		Prehypertension		Hypertension	
	B(95%CI)	P	B(95%CI)	P	B(95%CI)	P
Unadjusted model						
Normal glucose	Ref		Ref		Ref	
Prediabetes	42.12(19.83,64.40)	0.002	55.46(33.96,76.97)	<0.001	122.63(91.79,153.47)	<0.001
Diabetes	148.61(115.27,181.95)	<0.001	145.28(118.08,172.48)	<0.001	189.51(156.85,222.17)	<0.001
Adjusted model						
Normal glucose	Ref		Ref		Ref	
Prediabetes	7.55(-12.30,27.41)	0.459	33.42(14.38,52.46)	<0.001	69.6(41.85,97.35)	<0.001
Diabetes	53.48(16.13,90.83)	0.005	90.86(62.57,119.15)	<0.001	110.16(76.45,143.88)	<0.001

**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BP, blood pressure.

**Table S3** Interaction of blood pressure levels, blood glucose levels on baPWV

Blood pressure levels	Blood glucose levels	Unadjusted Model		Adjusted Model	
		B(95%CI)	P	B(95%CI)	P
Optimal BP	Normal glucose	Ref		Ref	
Optimal BP	Prediabetes	42.12(7.32,76.92)	0.018	5.96(-24.92,36.84)	0.705
Optimal BP	Diabetes	148.61(96.54,200.68)	<0.001	72.58(24.96,120.21)	0.003
Prehypertension	Normal glucose	167.01(140.37,193.65)	<0.001	111.01(87.14,134.89)	<0.001
Prehypertension	Prediabetes	222.48(194.76,250.19)	<0.001	143.84(118.58,169.10)	<0.001
Prehypertension	Diabetes	312.29(278.38,346.20)	<0.001	202.36(170.02,234.70)	<0.001
Hypertension	Normal glucose	353.49(325.30,381.69)	<0.001	287.95(260.16,315.73)	<0.001
Hypertension	Prediabetes	476.12(449.94,502.31)	<0.001	362.76(335.50,390.02)	<0.001
Hypertension	Diabetes	543(515.37,570.64)	<0.001	403.24(372.43,434.05)	<0.001
Interaction		21.15(8.79,33.51)	<0.001	19.71(8.68,30.73)	<0.001

**Abbreviation:** baPWV, brachial-ankle pulse wave velocity.

**Table S4** Interaction of physical exercise and the combined variable of blood pressure levels and blood glucose levels on baPWV

Blood pressure levels	Blood glucose levels	Inactive participants B(95%CI)	Sedentary participants B(95%CI)
Optimal BP	Normal glucose	Ref	Ref
Optimal BP	Prediabetes	13.69(-30.82,58.19)	0.31(-41.05,41.66)
Optimal BP	Diabetes	49.67(-21.73,121.06)	82.35(20.06,144.64)
Prehypertension	Normal glucose	113.53(79.10,147.95)	108.90(76.87,140.92)
Prehypertension	Prediabetes	139.80(173.56,275.59)	145.58(111.92,179.25)
Prehypertension	Diabetes	224.58(219.96,302.99)	193.12(151.61,234.62)
Hypertension	Normal glucose	261.47(281.07,365.38)	300.47(263.91,337.03)
Hypertension	Prediabetes	323.23(301.72,344.73)	377.40(342.01,412.80)
Hypertension	Diabetes	380.57(331.54,429.61)	410.17(370.66,449.69)
<i>P</i> for Interaction		0.083	

**Abbreviations:** baPWV, brachial-ankle pulse wave velocity; BP, blood pressure.

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