Relationship Between Brachial-Ankle Pulse Wave Velocity and Incident Hypertension According to 2017 ACC/AHA High Blood Pressure Guidelines

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Background—Arterial stiffness predicts both cardiovascular events and incident hypertension. However, whether brachial-ankle pulse wave velocity (baPWV) is predictive of incident hypertension based on the 2017 American College of Cardiology/American Heart Association (ACC/AHA) High Blood Pressure Guidelines has not been established. We performed a large cohort study to investigate whether incident hypertension could be predicted from baPWV measurements as a measure of arterial stiffness, even when applying updated hypertension criteria.

Methods and Results—A total of 10 360 Korean adults who underwent baPWV examination during a health-screening program between 2010 and 2016 were enrolled. Hypertension was defined according to the 2017 ACC/AHA Guidelines as 130/80 mm Hg. Cox proportional hazard analysis was used to assess the risk of incident hypertension according to baPWV quartiles. The mean age of the study subjects was 40.2 years and 75.6% were men. During the follow-up period (median 2.17 years), 2000 subjects (19.3%) developed hypertension. The subjects in the highest baPWV quartile group showed an increased risk of hypertension compared with the lowest baPWV quartile group as confirmed by multivariate adjusted hazard ratios of 1.64 (95% CI 1.41−1.89; *P*<0.001) in men and 12.36 (95% CI 4.41−34.62; *P*=0.005) in women. The increased risk of developing hypertension was consistent after adjusting for several confounding factors.

Conclusions—Arterial stiffness measured by baPWV is associated with incident hypertension according to the updated 2017 ACC/AHA Guidelines and is a useful independent predictor of incident hypertension among relatively healthy people. (*J Am Heart Assoc*. 2019;8:e013019. DOI: 10.1161/JAHA.119.013019.)

Key Words: arterial stiffness • atherosclerosis • brachial-ankle pulse wave velocity • hypertension

Blood pressure is a strong risk factor of cardiovascular events such as coronary heart disease, stroke, and peripheral artery disease.[1–3] Globally, the prevalence of hypertension is predicted to increase to a total of 1.56 billion

people.[4] Thus, early detection or prediction of hypertension is important from the perspective that cardiovascular disease is a leading cause of mortality, disability, and global healthcare costs.[5]

Arterial stiffness is one of the earliest detectable manifestations of adverse structural and functional changes within the vessel wall.[6] The relationship between arterial stiffness and hypertension has been reported in several studies.[7,8] Blood pressure and vascular stiffness are interdependent. Increased blood pressure can damage blood vessels and accelerate vascular stiffness, and arterial stiffening increases pressure pulsatility and systolic blood pressure.[9] Pulse wave velocity (PWV) is a reliable and noninvasive tool for measuring arterial stiffness. In addition, PWV is a reproducible, accurate, and negative prognostic factor of arterial stiffness.[10–12] Although carotid-femoral PWV has traditionally been widely used to identify associations with cardiovascular disease such as coronary artery disease, brachial-ankle pulse wave velocity (baPWV) has also become more widely used in recent years.[13–15]

The American College of Cardiology/American Heart Association (ACC/AHA) recently released revised guidelines for hypertension with lower blood pressure thresholds compared with previous guidelines (systolic blood pressure ≥130 versus 140 mm Hg or diastolic blood pressure ≥80 versus 90 mm Hg).[16,17] These changes are expected to increase the prevalence of patients with hypertension, especially in higher-risk populations compared with the general population.[18]

Although carotid-femoral PWV is the gold standard for estimating arterial stiffness,[19,20] baPWV has recently been reported to be correlated with carotid-femoral PWV.[15,21] In addition, baPWV is easy to measure, requiring no special techniques or training. In this study, we evaluated the relationship between arterial stiffness as measured by baPWV and incident hypertension based on revised guidelines. We assessed whether an increase in PWV could predict the onset of hypertension.

Methods

Study Subjects

The study population consisted of individuals registered in a comprehensive health screening program at Kangbuk Samsung Hospital, Seoul and Suwon, Korea. The purpose of the comprehensive health screening program was to improve health through early detection of chronic diseases and associated risk factors. This study analyzed people who, between 2010 and 2016, underwent baPWV testing as a part of their health-screening examination (Figure 1). Of the 17 665 individuals for which baPWV and associated data were initially available, we applied the following exclusion criteria: history of hypertension (n=4533); history of malignancy (n=861); history of cardiac surgery or cardiovascular disease (n=636); taking medicine for hypertension, diabetes mellitus, hyperlipidemia, or stroke (n=156); and age <0020 years (n=6). Finally, a total of 10 360 participants were eligible for inclusion in our study (7836 men and 2536 women; mean age, 40.2±7.2 years). The study protocol was approved by the Institutional Review Board of Kangbuk Samsung Hospital. Written informed consent was obtained from all participants. Data supporting the findings of this study are available from the corresponding author upon request.

Data Collection

All examinations were conducted at Kangbuk Samsung Health Screening Center clinics in Seoul and Suwon according to a standardized protocol. Blood was drawn from participants after fasting for at least 10 hours and analyzed at the Laboratory Medicine Department at the Kangbuk Samsung Hospital accredited by the Korean Association of Quality Assurance for Clinical Laboratories. Anthropometric measurements including height, weight, systolic blood pressure, and diastolic blood pressure were performed by well-trained examiners. Blood pressure was measured using an automated oscillometric device (53 000, Welch Allyn, New York) by trained nurses while participants were in a sitting position with their arm supported at heart level after a 5-minute rest. We recorded 3 consecutive blood pressure readings and used the average of the second and third readings for our analysis. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared.

Information about alcohol consumption (type of alcohol and glasses/day), smoking (never smoker, former smoker, or current smoker), frequency of vigorous exercise per week, and level of education were obtained from self-questionnaires. The baPWV measurement was recorded relative to conventional blood pressure at the same baseline clinic visit.

BaPWV measurements recorded in the supine position were obtained using a volume-plethysmography device (VP-1000, OMRON, Kyoto, Japan), which measures both brachial and posterior tibial artery pressure waveforms using an oscillometric method with cuffs placed around both arms and ankles of the participant. baPWV was calculated automatically by time-phase analysis, and the distance between the upper arm and ankle was estimated based on height. baPWV was obtained from right and left measurements, and the higher of the 2 readings were used for analysis.[22]

Prior history of surgery, drug, cerebrovascular disease, hypertension, hyperlipidemia, and diabetes mellitus was obtained by questionnaires. Hypertension was defined by systolic blood pressure ≥130 mm Hg, diastolic blood pressure ≥80 mm Hg, or current use of anti-hypertension medication.[16]
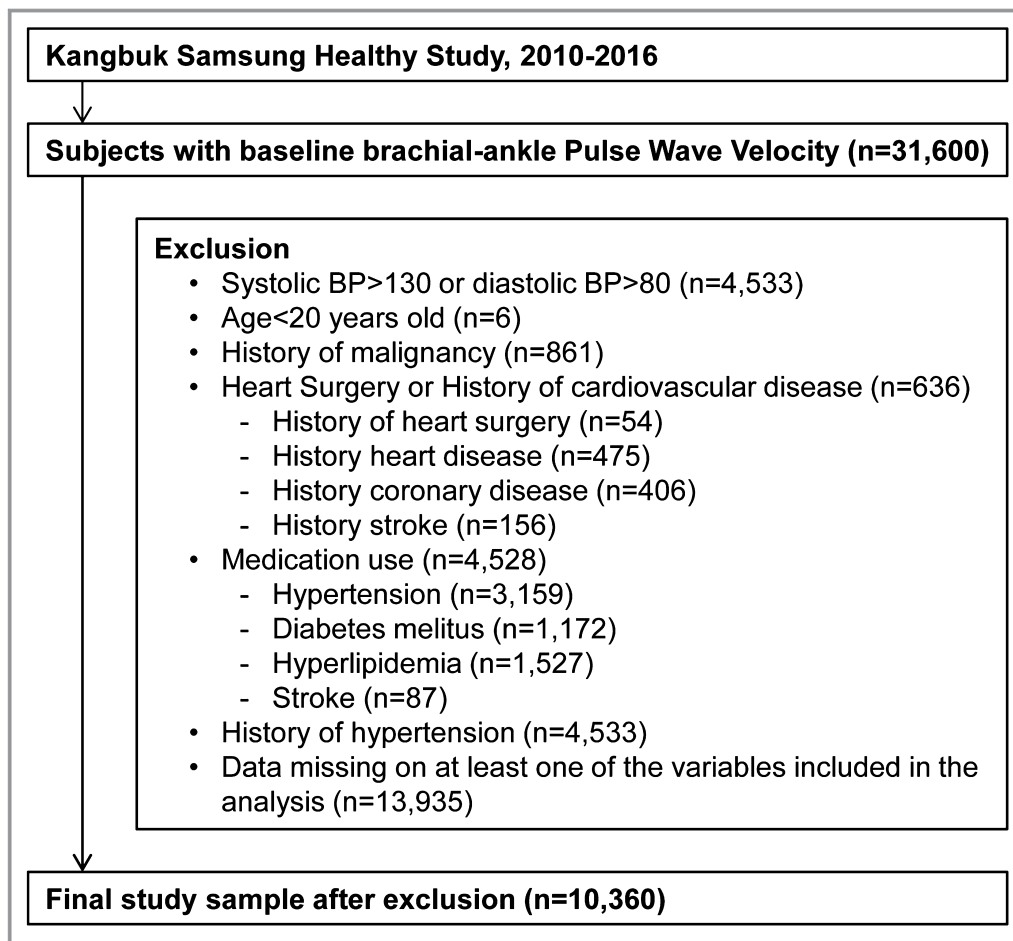

Kangbuk Samsung Healthy Study, 2010-2016

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Subjects with baseline brachial-ankle Pulse Wave Velocity (n=31,600)

Exclusion
- Systolic BP>130 or diastolic BP>80 (n=4,533)
- Age<20 years old (n=6)
- History of malignancy (n=861)
- Heart Surgery or History of cardiovascular disease (n=636)
  - History of heart surgery (n=54)
  - History heart disease (n=475)
  - History coronary disease (n=406)
  - History stroke (n=156)
- Medication use (n=4,528)
  - Hypertension (n=3,159)
  - Diabetes melitus (n=1,172)
  - Hyperlipidemia (n=1,527)
  - Stroke (n=87)
- History of hypertension (n=4,533)
- Data missing on at least one of the variables included in the analysis (n=13,935)

Final study sample after exclusion (n=10,360)

Figure 1. Flowchart summarizing the study population. BP indicates blood pressure.

Statistical Analysis

Comparisons of baseline characteristics and cardiovascular risk factors of the participants according to hypertension was performed using the following analysis method. Categorical variables are expressed as the number (%) and compared using the Pearson Chi-squared test. Continuous variables were expressed as mean (standard deviation) or median (interquartile range) if not normally distributed. For continuous variables, Student t-test or Mann–Whitney test were used to compare 2 groups, and ANOVA or Kruskal–Wallis tests were used for comparison of multiple groups as appropriate.

The final number of study participants without hypertension was categorized into 4 groups by baPWV. Cox proportional hazard analysis model was used to estimate adjusted hazard ratios (aHRs) and 95% CI for incident hypertension, adjusted for confounding factors identified from baseline characteristics. The predictive accuracy of each Cox model was determined by Harrell c-index.[23]

For analyses separated by sex and baPWV quartiles, we estimated aHRs for incident hypertension comparing the 3 highest quartiles of baPWV to the lowest quartile (reference group). In our analyses, we used 4 models to adjust for confounding factors: model 1 was adjusted for age, medical center, year of screening examination, smoking status, alcohol intake, vigorous exercise frequency and education level; model 2 was further adjusted for BMI; model 3 was further adjusted for systolic blood pressure; and model 4 was further adjusted for diastolic blood pressure.

We used Kaplan–Meier estimates to evaluate event rates over time according to baPWV quartiles, and used the log-rank test for analysis. The interaction effect between variables was also measured. All P values were 2-tailed, and $P<0.05$ was considered statically significant. Finally, we used receiver operating characteristic analysis to determine the baPWV cut point for incident hypertension. Statistical analyses were performed using Stata version 15.0 (Stata Corp. 2017, College Station, TX).

Results

We followed 10 360 non-hypertensive participants over a median period of 2.17 years (interquartile range, 1.74–3.63

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years). The mean participant age was 40.2±7.2 years, and 7836 (75.6%) were men. At the end of the follow-up period, 2000 (19.3%) participants developed hypertension according to the revised 2017 ACC/AHA guidelines.

Table 1 shows the baseline characteristics of the study population including metabolic markers divided into those who develop hypertension compared with those who do not. Participants who developed hypertension were older (42±6.8 versus 39.7±7.2 years) and more obese (BMI, 24.7±2.7 versus 23.1±2.8 kg/m^2; waist circumference, 86.1±7.5 versus 81.4±8.4 cm). With the exception of high-density lipoprotein cholesterol levels, all metabolic values were significantly higher in the hypertension group compared with the normotensive group. Compared with the normotensive group, the proportion of current smokers in the hypertension group was greater, while the level of education and the frequency of vigorous exercise was lower. Among participants who developed hypertension, men tended to be older than women (41.2±7.2 versus 37.1±6.2). In addition, systolic and diastolic BP were higher in men than in women (108.9±7.8 versus 98.9±8.6 mm Hg; 69.6±5.7 versus 63.5±6.6 mm Hg, respectively).

Tables 2 and 3 show the baseline characteristics of male and female patients in the hypertension population divided into baPWV quartiles. In general, the mean values of the systolic and diastolic blood pressures were highest among patients in the top baPWV quartile. This trend generally held true for other metabolic measurements in the top baPWV quartile as well.

The risk of incident hypertension increased progressively across baPWV quartiles in both men and women (Table 4). In the fully adjusted multivariate models, including adjustments for age, medical center, year of screening examination, smoking status, alcohol intake, exercise, education level, body mass index, systolic blood pressure and diastolic blood pressure, the aHRs (95% CI) for incident hypertension comparing the highest with the lowest quartiles (reference group) of baPWV were 1.64 (1.41–1.89) in men and 12.36 (4.41–34.62) in women, the difference of which was statistically significant. In this result, the aHRs in women have wide CIs, driven in large part by the chosen reference group having only 4 events. Because statistically operating at such small numbers could cause questions about the accuracy of large-sample approximations that provide the CIs used and *P* value, so we further analyzed baPWV in women by dividing them into 2 groups (Figure S1, Tables S1 and S2). As a result, the risk of incident hypertension was 76% higher in the group with higher baPWV than in the group with lower baPWV, which was statistically significant.

We used Harrell C-index to check the predictive power of the model with PWV in the incident hypertension risk, which was 0.823 (95% CI 0.812–0.836) for men and 0.894 (95% CI 0.855–0.934) for women.

Table 1. Baseline Characteristics of the Study Cohort Stratified by Incident Hypertension

Characteristics	No incident Hypertension (n=8360)	Hypertension (n=2000)	P Value
Age, y	39.7±7.2	42±6.8	<0.001
Sex			
Men	5941 (71.0)	1895 (94.7)	<0.001
Women	2419 (28.9)	105 (5.2)	
Glucose, mg/dL	92.0 (11.1)	95.1 (14.7)	<0.001
HbA1c, %	5.55 (0.35)	5.64 (0.49)	<0.001
AST (SGOT), IU/L	22.0 (11.9)	24.8 (12.6)	<0.001
ALT (SGPT), U/L	23.0 (17.9)	29.1 (24.5)	<0.001
GGT, IU/L	30.5 (30.6)	45.9 (44.0)	<0.001
Triglyceride, mg/dL	110.9 (69.9)	139.5 (79.6)	<0.001
HDL-C, mg/dL	56.7 (14.6)	51.9 (12.4)	<0.001
LDL-C, mg/dL	120.8 (30.4)	129.5 (29.5)	<0.001
Uric acid, mg/dL	5.4 (1.3)	6.0 (1.2)	<0.001
hsCRP, mg/L	0.09 (0.28)	0.11 (0.29)	<0.001
Insulin, IU/mL	5.31 (3.06)	5.94 (3.61)	<0.001
HOMA-IR	1.23 (0.79)	1.42 (0.99)	<0.001
BMI, kg/m^2	23.1 (2.8)	24.7 (2.7)	<0.001
Waist, cm	81.4 (8.4)	86.1 (7.5)	<0.001
Systolic BP, mm Hg	105.1 (9.0)	112.3 (6.9)	<0.001
Diastolic BP, mm Hg	67.0 (6.3)	72.7 (4.8)	<0.001
Education level			
≥College graduate	7246 (86.6)	1717 (85.8)	0.02
≤High school	774 (9.2)	174 (8.7)	
Unknown	340 (4.0)	109 (5.4)	
Smoking status			
Never/former smoker	5858 (70.1)	1188 (59.4)	<0.001
Current smoker	2338 (28.0)	787 (39.3)	
Unknown	164 (2.0)	25 (1.2)	
Alcohol, g/day	3.0 (7.0–18.0)	6.0 (14.0–34.0)	<0.001
Vigorous exercise frequency			
<1 time/wk	5163 (61.7)	1108 (55.4)	<0.001
≥1 time/wk	3117 (37.2)	869 (43.4)	
Unknown	80 (0.9)	23 (1.1)	

Data are presented as n (%) or mean±SD or median (interquartile range). ALT indicates alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; BP, blood pressure; GGT, gamma glutamyl transferase; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; hsCRP, high-sensitivity C-reactive protein; LDL-C, low-density lipoprotein cholesterol; SGOT, serum glutamic-oxaloacetic transaminase; SGPT, serum glutamate-pyruvate transaminase.

The Kaplan–Meier curves for risk of incident hypertension according to baPWV quartiles are shown in Figure 2. The rate was higher for groups with higher baPWV values in

Table 2. Baseline Characteristics of the Male Study Cohort Stratified by baPWV Quartile

| Characteristics | PWV Quartiles, cm/s | | | | P Value |
	Q1 (865-1218) (n=1945)	Q2 (1219-1301) (n=1962)	Q3 (1302-1388) (n=1956)	Q4 (1389-2468) (n=1973)	
Age, y	39.7 (6.4)	40.6 (6.5)	41.3 (6.7)	43.0 (8.4)	<0.001
Glucose, mg/dL	92.2 (10.0)	93.1 (11.3)	94.8 (14.8)	95.2 (13.9)	<0.001
HbA1c, %	5.55 (0.32)	5.57 (0.35)	5.61 (0.46)	5.63 (0.47)	<0.001
AST (SGOT), IU/L	23.4 (15.5)	23.1 (9.6)	24.2 (13.7)	24.6 (10.7)	<0.001
ALT (SGPT), IU/L	26.2 (23.7)	26.0 (16.6)	27.5 (19.2)	28.7 (19.4)	<0.001
GGT, IU/L	34.5 (35.5)	37.0 (31.5)	40.4 (36.7)	43.4 (40.8)	<0.001
Triglyceride, mg/dL	120.0 (69.1)	124.0 (70.2)	132.3 (81.1)	139.1 (83.5)	<0.001
HDL-C, mg/dL	52.6 (12.2)	52.9 (12.8)	52.2 (12.8)	52.3 (12.5)	0.321
LDL-C, mg/dL	124.9 (29.6)	125.9 (28.9)	128.3 (29.1)	131.0 (30.4)	<0.001
Uric acid, mg/dL	6.00 (1.15)	6.01 (1.17)	5.99 (1.18)	6.03 (1.17)	0.720
hsCRP, mg/L	0.09 (0.19)	0.10 (0.24)	0.11 (0.33)	0.12 (0.36)	0.006
Insulin, IU/mL	5.40 (3.24)	5.41 (3.04)	5.58 (3.29)	5.72 (3.31)	0.005
HOMA-IR	1.25 (0.82)	1.26 (0.78)	1.33 (0.93)	1.37 (0.91)	<0.001
BMI, kg/m^2	24.45 (2.79)	24.16 (2.53)	24.03 (2.58)	23.92 (2.58)	<0.001
Waist, cm	85.3 (7.5)	84.8 (6.8)	84.6 (7.1)	84.6 (7.1)	0.008
Systolic BP, mm Hg	106.5 (7.9)	108.2 (7.6)	109.6 (7.5)	111.4 (7.5)	<0.001
Diastolic BP, mm Hg	67.8 (5.9)	69.3 (5.6)	70.2 (5.4)	71.2 (5.3)	<0.001
Education level					
≥College graduate	1798 (92.4)	1800 (91.7)	1716 (87.7)	1667 (89.0)	<0.001
≤High school	90 (4.6)	107 (5.4)	141 (7.2)	168 (8.5)	
Unknown	57 (2.9)	55 (2.8)	99 (5.0)	138 (6.9)	
Smoking status					
Never/former smoker	1184 (60.9)	1152 (58.7)	1153 (58.9)	1169 (59.2)	0.059
Current smoker	743 (38.2)	785 (40.0)	769 (39.3)	764 (38.7)	
Unknown	17 (0.8)	25 (1.2)	34 (1.7)	40 (2.0)	
Alcohol, g/day	4.0 (11.0–23.0)	5.0 (11.0–27.0)	5.0 (11.0–27.0)	5.0 (11.0–27.0)	0.026
Vigorous exercise frequency					
<1 time/wk	1024 (52.6)	1086 (55.3)	1105 (56.4)	1155 (58.5)	0.001
≥1 time/wk	910 (46.7)	850 (43.3)	835 (42.6)	795 (40.2)	
Unknown	11 (0.5)	26 (1.3)	16 (0.8)	23 (1.1)	

Data are presented as n (%) or mean±SD or median (interquartile range). ALT indicates alanine aminotransferase; AST, aspartate aminotransferase; baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; GGT, gamma glutamyl transferase; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; hsCRP, high-sensitivity C-reactive protein; LDL-C, low-density lipoprotein cholesterol; SGOT, serum glutamic-oxaloacetic transaminase; SGPT, serum glutamate-pyruvate transaminase.

both men and women (*P*<0.001) (Figure 2). The results were similar when changing the cutoffs of blood pressure to define hypertension (systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg; Figure S2, Table S3 through S6). The interaction between baseline blood pressure, baPWV, and incident hypertension was illustrated by 2-dimensional plot by quartiles of baPWV and quartiles of baseline systolic blood pressure (Figure 3, Table S7).

No significant interactions were observed between baPWV and any of the subgroups with respect to the incidence of hypertension, as shown in the hazard-ratio plots in Figure 4. In addition, we used the Youden Index on the receiver operating characteristic curve to determine the baPWV cut point for predicting incident hypertension.[24] As a result, the baPWV cut point for predicting incident hypertension was 1319 cm/s for male (sensitivity: 58.5%, specificity: 59.7%) and 1246 cm/s (sensitivity: 69.5%, specificity: 69.5%) for

Table 3. Baseline Characteristics of the Female Study Cohort Stratified by baPWV Quartile.

Characteristics	PWV Quartiles, cm/s				P Value
	Q1 (781–1104) (n=625)	Q2 (1105–1188) (n=626)	Q3 (1189–1272) (n=639)	Q4 (1273–1961) (n=634)	
Age, y	35.0 (4.9)	36.4 (5.4)	37.3 (5.9)	39.9 (7.3)	<0.001
Glucose, mg/dL	87.8 (7.4)	88.5 (7.2)	88.5 (7.6)	89.8 (8.8)	0.0001
HbA1c, %	5.46 (0.25)	5.49 (0.26)	5.48 (0.26)	5.54 (0.30)	<0.001
AST (SGOT), IU/L	17.9 (5.9)	18.4 (6.4)	19.0 (14.3)	19.0 (8.6)	0.100
ALT (SGPT), IU/L	14.0 (9.5)	14.9 (10.4)	16.0 (24.2)	15.5 (9.7)	0.113
GGT, IU/L	15.1 (12.8)	16.0 (12.3)	17.2 (22.7)	18.6 (17.2)	0.001
Triglyceride, mg/dL	73.0 (32.9)	75.8 (42.5)	75.6 (34.0)	86.7 (44.5)	<0.001
HDL-C, mg/dL	66.7 (14.6)	66.2 (13.7)	66.9 (14.8)	64.8 (15.0)	0.045
LDL-C, mg/dL	101.7 (24.5)	105.5 (26.8)	105.8 (25.9)	113.7 (29.9)	<0.001
Uric acid, mg/dL	4.16 (0.89)	4.18 (0.83)	4.25 (0.85)	4.22 (0.85)	0.322
hsCRP, mg/L	0.07 (0.21)	0.07 (0.18)	0.07 (0.21)	0.09 (0.36)	0.243
Insulin, IU/mL	5.03 (2.89)	5.09 (2.99)	5.04 (2.96)	5.30 (3.25)	0.344
HOMA-IR	1.11 (0.68)	1.13 (0.73)	1.12 (0.73)	1.20 (0.79)	0.145
BMI, kg/m^2	21.47 (2.93)	21.32 (2.72)	21.31 (2.95)	21.68 (2.89)	0.07
Waist, cm	74.09 (7.54)	74.20 (7.70)	74.56 (7.84)	75.36 (7.56)	0.014
Systolic BP, mm Hg	95.6 (7.9)	97.3 (8.0)	99.1 (7.9)	103.8 (8.5)	<0.001
Diastolic BP, mm Hg	60.8 (6.1)	62.4 (6.3)	63.9 (6.1)	66.8 (6.3)	<0.001
Education level					0.003
≥College graduate	509 (81.4)	494 (78.9)	515 (80.5)	464 (73.1)	
≤High school	98 (15.6)	105 (16.7)	95 (14.8)	144 (22.7)	
Unknown	18 (2.8)	27 (4.3)	29 (4.5)	26 (4.1)	
Smoking status					0.001
Never/former smoker	605 (96.8)	602 (96.1)	597 (93.4)	583 (91.9)	
Current smoker	13 (2.0)	12 (1.9)	17 (2.6)	22 (3.4)	
Unknown	7 (1.1)	12 (1.9)	25 (3.9)	29 (4.5)	
Alcohol, g/day	1.0 (3.0–7.0)	0.0 (3.0–6.0)	0.0 (3.0–6.0)	0.0 (3.0–7.0)	0.422
Vigorous exercise frequency					0.757
<1 time/wk	473 (75.6)	481 (76.8)	483 (75.5)	464 (73.1)	
≥1 time/wk	147 (23.5)	137 (21.8)	150 (23.4)	162 (25.5)	
Unknown	5 (0.8)	8 (1.2)	6 (0.9)	8 (1.2)	

Data are presented as n (%) or mean±SD or median (interquartile range). ALT indicates alanine aminotransferase; AST, aspartate aminotransferase; baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; GGT, gamma glutamyl transferase; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; hsCRP, high-sensitivity C-reactive protein; LDL-C, low-density lipoprotein cholesterol; SGOT, serum glutamic-oxaloacetic transaminase; SGPT, serum glutamate-pyruvate transaminase.

female. The Harrell C-index was not significantly increased when baPWV is added to a Model 4 in Table 4.

Discussion

The American College of Cardiology/American Heart Association (ACC/AHA) recently released revised guidelines[16] for hypertension. These guidelines consist of lower blood pressure thresholds (systolic blood pressure ≥130 mm Hg or diastolic blood pressure ≥80 mm Hg) than previous guidelines (systolic blood pressure ≥130 mm Hg or diastolic blood pressure ≥80 mm Hg).[25] Adopting the 2017 ACC/AHA high blood pressure guidelines is expected to markedly increase the number of people labeled as having hypertension and treated with medication in both the US and China. Indeed, according to these criteria, more than half of those aged 45 to 75 years in both countries can be considered as hypertensive.[26] Accordingly, the usefulness of previously studied tools may also change as patients with perhaps greater risk than

Table 4. Risk of Incident Hypertension According to baPWV in Men and Women

	Person-Years	Events (No.)	Incident Rate (10 000 person-years)	Age-Adjusted HR (95% CI)	Multivariable-Adjusted HR* (95% CI)			
					Model 1	Model 2	Model 3	Model 4
Men								
Q1	5360.3	284	529.8	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Q2	5763.7	409	709.6	1.27 (1.09–1.48)	1.38 (1.18–1.60)	1.41 (1.21–1.65)	1.32 (1.13–1.54)	1.23 (1.05–1.43)
Q3	5851.4	527	900.6	1.61 (1.39–1.86)	1.72 (1.49–1.99)	1.79 (1.55–2.07)	1.59 (1.37–1.84)	1.45 (1.25–1.68)
Q4	5835.8	675	1156.6	2.06 (1.79–2.37)	2.16 (1.88–2.49)	2.28 (1.98–2.62)	1.8 (1.55–2.08)	1.64 (1.41–1.89)
Women								
Q1	1503.8	4	26.5	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Q2	1532.2	17	110.9	3.81 (1.28–11.34)	3.68 (1.23–10.97)	3.81 (1.28–11.34)	3.68 (1.23–10.97)	4.2 (1.41–12.55)
Q3	1542.5	22	142.6	4.74 (1.63–13.80)	4.98 (1.71–14.56)	4.74 (1.63–13.8)	4.98 (1.71–14.56)	5.12 (1.75–14.98)
Q4	1525.8	62	406.3	11.09 (3.96–31.05)	11.11 (3.97–31.11)	11.09 (3.96–31.05)	11.11 (3.97–31.11)	12.36 (4.41–34.62)

baPWV indicates brachial-ankle pulse wave velocity; HR, hazard ratio.
*Model 1: adjustment for age, medical center, year of screening examination, smoking status, alcohol intake, exercise and educationa level; Model 2: Model 1 and adjustment for BMI; Model 3: Model 2 and adjustment for systolic blood pressure; Model 4: Model 3 and adjustment for diastolic blood pressure.

the general population become newly included in high blood pressure groups.

In the present study, we evaluate the relationship between blood pressure and baPWV reflective of arterial stiffness among a large cohort of young and middle-aged asymptomatic adults. There were 3 main findings of our study. First, baPWV as a measure of arterial stiffness was independently associated with development of hypertension even under the new 2017 ACC/AHA guidelines. Second, we found that women were at higher risk than men with respect to developing hypertension according to baPWV.

We evaluated the association between high blood pressure and baPWV as a representative marker of arterial stiffness.[27]

Several studies have utilized PWV as a predictor of cardiovascular disease,[28–30] and carotid-femoral PWV has traditionally been used as a standard method to evaluate vascular damage and cardiovascular disease. However, several recent studies have also demonstrated the effectiveness and validity of baPWV for vascular damage and cardiovascular disease as well.[15,21,31,32] Importantly, measuring baPWV does not require any specialized techniques, and instead is automatically measured by wrapping cuffs on the brachium and ankle. Because of this simple measurement method, baPWV can be used in health examination programs, resulting in higher utilization as a predictive tool.

Arterial stiffness is one of the earliest detectable manifestations of adverse structural and functional changes within
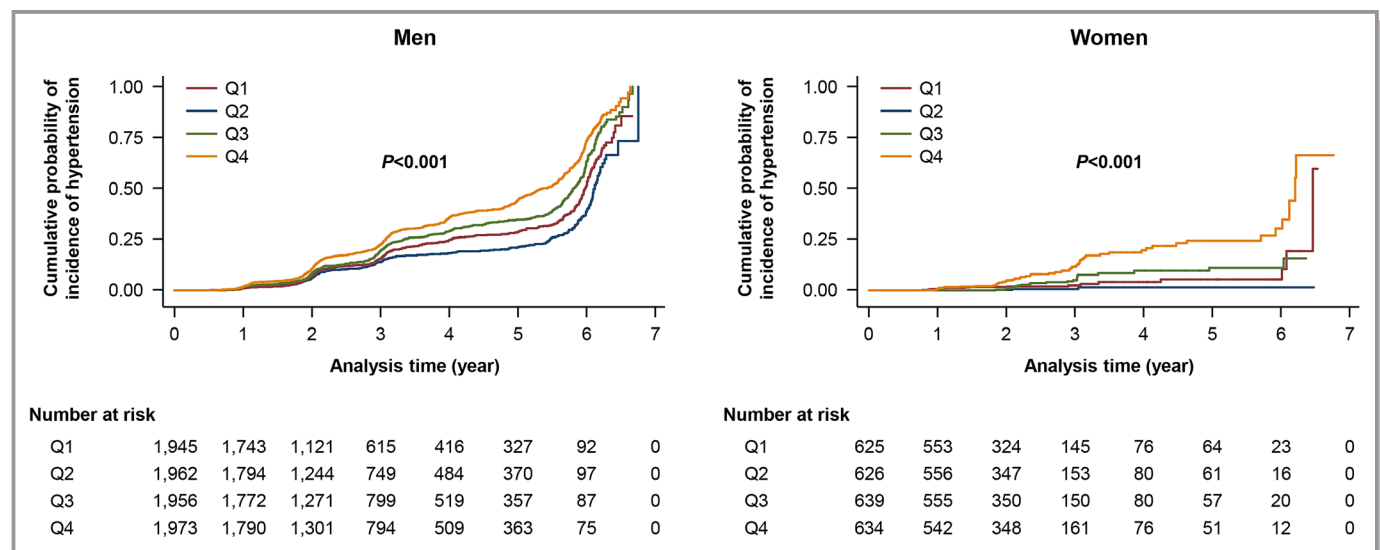

Figure 2. Kaplan–Meier Curves for incident hypertension according to baPWV in men and women. baPWV indicates brachial-ankle pulse wave velocity.
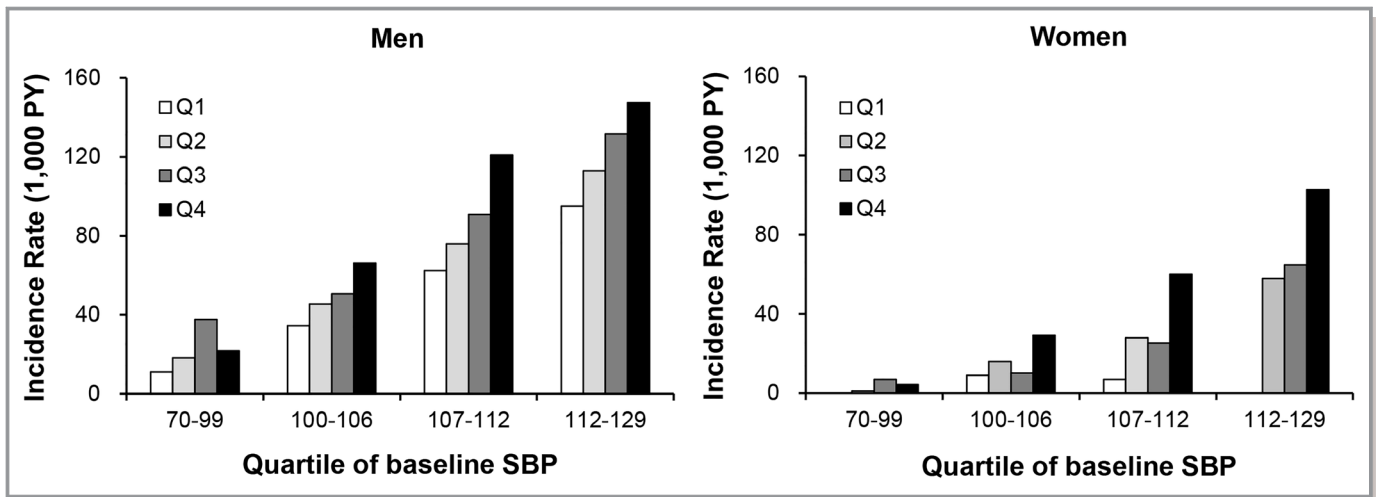
Figure 3. Incident hypertension rate by quartiles of baPWV and quartiles of baseline systolic blood pressure. baPWV indicates brachial-ankle pulse wave velocity; SBP, systolic blood pressure; PY, person-years.

the vessel wall.[6] There are several mechanisms of arterial stiffness, including vascular growth factor expression, calcification, inflammation, and environmental factors.[26,33–35] Arterial stiffness increases as a complication of hypertension, whereas more recent studies have shown that arterial stiffness contributes to hypertension. Thus, early diagnosis of arterial stiffness may provide insight into future disease, including hypertension.

Several earlier studies have shown that arterial stiffness is associated with hypertension.[8,36–38] However there are limitations, in that the studies were relatively small in number or did not adjust for socioeconomic status. In addition, their study did not utilize the new 2017 ACC/AHA criteria.

The results of our study are consistent with those from previous studies on the association between arterial stiffness and hypertension. The increased risk of incident hypertension
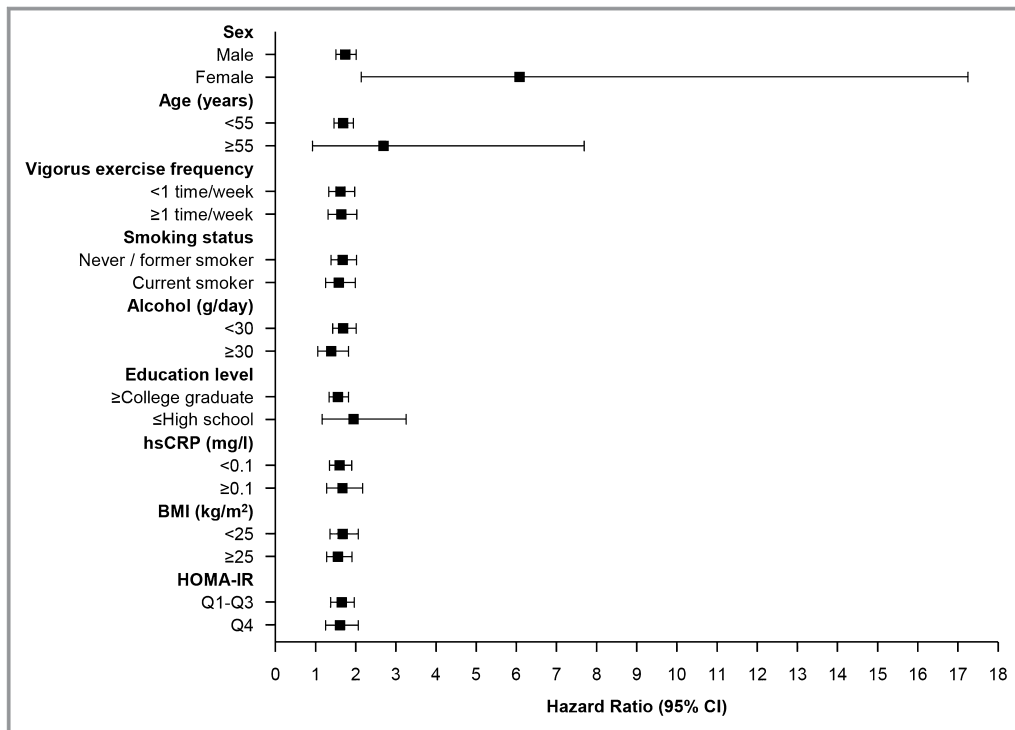

Figure 4. Subgroup analyses of incident hypertension according to baPWV. baPWV indicates brachial-ankle pulse wave velocity; BMI, bone mass index, HOMA-IR, homeostasis model assessment of insulin resistance; hsCRP, high-sensitivity C-reactive protein.

in those individuals in the greatest baPWV quartile was the same for both men and women, and this result was maintained even after multivariable adjustment. Some of the strengths of this study relative to prior studies were the relatively large number participants (n=10 360), use of new hypertension guidelines, and adjusting for socioeconomic status.

Study Limitations

The results of this study should be interpreted in the context of several potential limitations. First, the diagnosis of hypertension were based on measurements taken at a single visit, which may be unreliable and lead to misclassification of blood pressure status. Well-trained examiners measured blood pressure 3 times using the standard method of measurement, but we cannot completely rule out white coat or masked hypertension that may occur in some patients. The 24-hour ambulatory BP measurement can be used as a good tool to rule out white coat or masked hypertension. Unfortunately, we didn't measure 24-hour ambulatory BP to confirm hypertension, so we couldn't completely rule out the possibility of white coat or masked hypertension. Second, although we adjusted for age, BMI, smoking status, blood pressure, and several other possible risk factors, we could not exclude all possible residual confounding factors. To address this limitation, we performed multivariate analysis to account for confounding factors. Third, there is a notable dispersion at the end of the follow-up period across baPWV quartiles. When referring to Kaplan Meier plots in Figure 2, the difference in the number at risk between Q1 and Q4 for men at year 3 is (794−615)/615=29%. However, the absolute difference in cumulative incidence of hypertension between Q1 and Q4 is $\approx$ 10%. This result can be interpreted as likely to have visited patients in Q4 more frequently, which suggests the possibility of ascertainment bias. The Occupational Safety and Health Act in Korea require employers to conduct annual or biennial health examinations of all employees, and employees are required to participate. About 80 percent of the population who participated in this study were conducted under the Occupational Safety and Health Act in Korea, so there is little room for individual will to intervene. However, since the remaining 20% were the people who underwent medical checkups on their own, it is likely that these people underwent medical checkups more frequently. For this reason, there is a possibility that ascertainment bias has occurred. Fourth, our study consisted of relatively healthy young middle-aged subjects. Therefore, it may be unreasonable to generalize our results to the entire population. Accordingly, our findings may differ for different age groups or patients from other races/ethnicities beyond Korea. Fifth, we did not measure the heart rate when collecting baPWV results. Heart rate is known as an important confounding factor in interpreting

PWV results.[39] Therefore, in this study, it was also necessary to analyze the results by adding heart rate as a covariate to the model. Finally, there is a possibility that the blood pressure measurements may not be an accurate reflection of the true blood pressure and this may influence findings.[40] However, several aspects of this large cohort study add significant strength to our findings. The participants in this study were generally young and healthy, and thus may be less biased to use of medications or co-morbidities that affect elderly individuals. In addition, the data were collected by well-trained expert staff according to standardized and uniform conditions.

Conclusions

We found that baPWV, as a measurement of arterial stiffness, was strongly and independently correlated with hypertension among relatively healthy people. In addition, baPWV was predictive of incident hypertension in patients with known risk factors.

Acknowledgments

Disclosures

None.

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SUPPLEMENTAL MATERIAL

Table S1. Baseline Characteristics of the Female Study Cohort Stratified by dichotomizing baPWV.

Characteristics	baPWV (cm/sec)		*P* value
	Q1-2 (781-1188) (n=1,251, 49.6%)	Q3-4 (1189-1961) (n=1,273, 50.4%)	
Age (years)	35.7 (5.2)	38.6 (6.8)	<0.001
Glucose (mg/dL)	88.2 (7.3)	89.2 (8.3)	0.001
HbA1c (%)	5.48 (0.3)	5.52 (0.3)	0.003
AST (SGOT) (IU/L)	18.2 (6.2)	19.1 (11.8)	0.021
ALT (SGPT) (IU/L)	14.5 (10)	15.8 (18.5)	0.035
GGT (IU/L)	15.6 (12.6)	18.0 (20.2)	<0.001
Triglyceride (mg/dl)	74.5 (38.1)	81.2 (40)	<0.001
HDL-C (mg/dl)	66.5 (14.3)	65.9 (15)	0.295
LDL-C (mg/dl)	103.6 (25.8)	109.8 (28.3)	<0.001
Uric acid (mg/dl)	4.18 (0.9)	4.24 (0.9)	0.083
hsCRP (mg/l)	0.07 (0.2)	0.09 (0.3)	0.171
Insulin (IU/ml)	5.07 (2.9)	5.18 (3.1)	0.366
HOMA-IR	1.13 (0.7)	1.16 (0.8)	0.195
BMI (kg/m^2)	21.4 (2.8)	21.5 (2.9)	0.377
Waist (cm)	74.1 (7.6)	75.0 (7.7)	0.008
Systolic BP (mmHg)	96.5 (8.0)	101.5 (8.6)	<0.001
Diastolic BP (mmHg)	61.7 (6.3)	65.4 (6.4)	<0.001
Education level			0.133
≥College graduate	1,003 (80.2)	979 (76.9)	

≤High school	203 (16.2)	239 (18.8)	
Unknown	45 (3.6)	55 (4.3)	
Smoking status			<0.001
Never / former smoker	1,207 (96.5)	1,180 (92.7)	
Current smoker	25 (2)	39 (3.1)	
Unknown	19 (1.5)	54 (4.2)	
Alcohol (g/day)	3 (0-6)	3 (0-7)	0.690
Vigorous exercise frequency			0.553
<1 time/week	954 (76.3)	947 (74.4)	
≥1 time/week	284 (22.7)	312 (24.5)	
Unknown	13 (1.0)	14 (1.1)	

Data are presented as n (%) or mean±SD or median (IQR).

ALT, alanine aminotransferase; AST, aspartate aminotransferase; baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; GGT, gamma glutamyl transferase; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; HTN, hypertension; LDL-C, low-density lipoprotein cholesterol.

Table S2. Risk of Incident HTN According to baPWV in Men and Women.

| | Person-years | Events (No.) | Incident rate (10,000 person-years) | Age-adjusted HR (95% CI) | Multivariable-adjusted HR[*] (95% CI) | | | |
					Model 1	Model 2	Model 3	Model 4
Men								
Q1	5,360.3	284	529.8	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Q2	5,763.7	409	709.6	1.27 (1.09-1.48)	1.38 (1.18-1.60)	1.41 (1.21-1.65)	1.32 (1.13-1.54)	1.23 (1.05-1.43)
Q3	5,851.4	527	900.6	1.61 (1.39-1.86)	1.72 (1.49-1.99)	1.79 (1.55-2.07)	1.59 (1.37-1.84)	1.45 (1.25-1.68)
Q4	5,835.8	675	1156.6	2.06 (1.79-2.37)	2.16 (1.88-2.49)	2.28 (1.98-2.62)	1.8 (1.55-2.08)	1.64 (1.41-1.89)
Women								
Q1-2	3,036.0246	21	69.17	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Q3-4	3,068.449	84	273.75	3.12 (1.90-5.11)	3.33 (2.03-5.47)	3.32(2.02-5.44)	1.95 (1.16-3.26)	1.76 (1.05-2.94)

baPWV, brachial-ankle pulse wave velocity; CI, confidence interval; HR, hazard ratio; HTN, hypertension.

[*]Model 1: adjustment for age, medical center, year of screening examination, smoking status, alcohol intake, exercise and educational level;

Model 2: Model 1 and adjustment for BMI; Model 3: Model 2 and adjustment for SBP; Model 4: Model 3 and adjustment for DBP.

Table S3. Baseline Characteristics of the Cohort Stratified by Incident HTN.

Characteristics	No incident HTN (n=12,427)	HTN (n=1,095)	P value
Age (years)	40.5±7.2	42.8±7.3	<0.001
Sex			<0.001
Male	9,789 (78.77)	1,053 (96.16)	
Female	2,638 (21.23)	42 (3.84)	
Glucose (mg/dL)	93.1 (12.1)	95.9 (12.6)	<0.001
HbA1c (%)	5.57 (0.38)	5.67 (0.41)	<0.001
AST (SGOT) (IU/L)	23.0 (11.9)	26.7 (17.2)	<0.001
ALT (SGPT) (IU/L)	25.0 (18.8)	32.5 (29.6)	<0.001
GGT (IU/L)	35.4 (35.7)	54.3 (57.4)	<0.001
Triglyceride (mg/dl)	121.4 (77.7)	157.0 (119.1)	<0.001
HDL-C (mg/dl)	55.3 (14.2)	50.7 (12.4)	<0.001
LDL-C (mg/dl)	123.6 (30.4)	131.8 (31.4)	<0.001
Uric acid (mg/dl)	5.65 (1.35)	6.22 (1.24)	<0.001
hsCRP (mg/l)	0.10 (0.29)	0.13 (0.34)	<0.001
Insulin (IU/ml)	5.60 (3.39)	6.58 (3.71)	<0.001
HOMA-IR	1.31 (0.90)	1.59 (1.00)	<0.001
BMI (kg/m^2)	23.7 (2.9)	25.3 (2.8)	<0.001
Waist circumference (cm)	82.9 (8.5)	87.6 (7.9)	<0.001
Systolic BP (mmHg)	109.2 (10.6)	121.2 (8.2)	<0.001
Diastolic BP (mmHg)	70.7 (8.1)	79.8 (6.2)	<0.001
Education level			0.021
≥College graduate	10,799 (86.90)	923 (84.29)	

≤High school	1,125 (9.05)	111 (10.14)	
Unknown	503 (4.05)	61 (5.57)	
Smoking status			<0.001
Never / former smoker	8,423 (67.78)	636 (58.08)	
Current smoker	3,799 (30.57)	440 (40.18)	
Unknown	205 (1.65)	19 (1.74)	
Alcohol (g/day)	10.0 (3.0-23.0)	17.0 (7.0-34.0)	<0.001
Vigorous exercise frequency			0.020
<1 time/week	7,405 (59.59)	607 (55.43)	
≥1 time/week	4,914 (39.54)	475 (43.38)	
Unknown	108 (0.87)	13 (1.19)	

Data are presented as n (%) or mean±SD or median (IQR).

Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥ 90 mmHg.

ALT, alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; BP, blood pressure; GGT, gamma glutamyl transferase; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; HTN, hypertension; LDL-C, low-density lipoprotein cholesterol.

Table S4. Baseline Characteristics of the Cohort Stratified by baPWV Quartile in Men.

Characteristics	baPWV quartiles (cm/sec)				
	Q1 (865-1235) (n=2,697)	Q2 (1236-1321) (n=2,702)	Q3 (1322-1413) (n=2,712)	Q4 (1414-2993) (n=2,731)	P value
Age (years)	39.9 (6.3)	41.0 (6.6)	41.5 (6.6)	43.7 (8.6)	<0.001
Glucose (mg/dL)	92.6 (9.8)	93.8 (12.1)	94.7 (13.6)	96.4 (14.5)	<0.001
HbA1c (%)	5.56 (0.31)	5.59 (0.38)	5.61 (0.41)	5.65 (0.48)	<0.001
AST (SGOT) (IU/L)	23.5 (15.0)	23.8 (11.1)	24.6 (12.6)	25.7 (12.5)	<0.001
ALT (SGPT) (IU/L)	26.6 (22.1)	27.1 (17.6)	28.7 (19.5)	30.3 (21.5)	<0.001
GGT (IU/L)	36.2 (42.7)	39.5 (35.2)	43.5 (38.3)	48.2 (43.8)	<0.001
Triglyceride (mg/dl)	123.7 (72.2)	128.6 (74.0)	140.5 (90.4)	149.1 (101.9)	<0.001
HDL-C (mg/dl)	52.3 (12.2)	52.5 (12.9)	51.9 (12.5)	52.0 (12.5)	0.247
LDL-C (mg/dl)	125.6 (29.6)	127.0 (29.2)	128.9 (29.4)	132.0 (30.8)	<0.001
Uric acid (mg/dl)	6.02 (1.16)	6.02 (1.16)	6.06 (1.22)	6.12 (1.21)	0.005
hsCRP (mg/l)	0.98 (0.22)	0.10 (0.25)	0.11 (0.34)	0.13 (0.37)	<0.001
Insulin (IU/ml)	5.55 (3.42)	5.66 (3.28)	5.85 (3.38)	6.18 (3.78)	<0.001
HOMA-IR	1.29 (0.88)	1.33 (0.85)	1.39 (0.92)	1.50 (1.06)	<0.001
BMI (kg/m^2)	24.61 (2.81)	24.34 (2.62)	24.35 (2.67)	24.33 (2.71)	<0.001
Waist (cm)	85.6 (7.5)	85.2 (7.1)	85.3 (7.3)	85.5 (7.3)	0.193
Systolic BP (mmHg)	108.6 (9.0)	111.6 (9.3)	113.7 (9.1)	116.8 (9.3)	<0.001
Diastolic BP (mmHg)	69.9 (7.3)	72.4 (7.3)	74.0 (7.2)	76.2 (7.1)	<0.001
Education level					<0.001
≥College graduate	2,492 (92.4)	2,448 (90.60)	2,415 (89.05)	2,275 (83.30)	
≤High school	133 (4.93)	161 (5.96)	185 (6.82)	277 (10.14)	

Unknown	72 (2.67)	93 (3.44)	112 (4.13)	179 (6.55)	
Smoking status					0.021
Never / former smoker	1,643 (60.92)	1,629 (60.29)	1,640 (60.49)	1,616 (59.17)	
Current smoker	1,034 (38.34)	1,033(38.23)	1,037 (38.24)	1,063 (38.92)	
Unknown	20 (0.74)	40 (1.48)	35 (1.29)	52 (1.90)	
Alcohol (g/day)	11 (4.0-24.0)	12 (5.0-28.0)	14.0 (6.0-29.0)	13.0 (5.0-28.0)	<0.001
Vigorous exercise frequency					<0.001
<1 time/week	1,417 (52.54)	1,460 (54.03)	1,541 (56.82)	1,572 (57.56)	
≥1 time/week	1,263 (46.83)	1,214 (44.93)	1,153 (42.51)	1,128 (41.30)	
Unknown	17 (0.63)	28 (1.04)	18 (0.66)	31 (1.14)	

Data are presented as n (%) or mean±SD or median (IQR).

Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg.

ALT, alanine aminotransferase; AST, aspartate aminotransferase; baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; GGT, gamma glutamyl transferase; HbA1c, hemoglobin A1c; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; HTN, hypertension; LDL-C, low-density lipoprotein cholesterol.

Table S5. Baseline Characteristics of the Cohort Stratified by baPWV Quartile in Women.

Characteristics	baPWV quartiles (cm/sec)				
	Q1 (781-1110) (n=670)	Q2 (1111-1197) (n=664)	Q3 (1198-1282) (n=671)	Q4 (1283-2092) (n=675)	P value
Age (years)	35.1 (5.0)	36.5 (5.3)	37.6 (6.2)	40.4 (7.5)	<0.001
Glucose (mg/dL)	87.9 (7.9)	88.7 (7.2)	88.6 (7.5)	90.5 (9.4)	0.0001
HbA1c (%)	5.47 (0.26)	5.49 (0.26)	5.50 (0.26)	5.55 (0.31)	<0.001
AST (SGOT) (IU/L)	18.1 (6.5)	18.3 (6.3)	19.2 (14.5)	19.3 (7.8)	0.050
ALT (SGPT) (IU/L)	14.6 (11.9)	14.7 (9.7)	16.1 (23.8)	15.8 (9.6)	0.171
GGT (IU/L)	15.3 (13.0)	16.0 (12.5)	17.3 (22.2)	19.4 (18.3)	<0.001
Triglyceride (mg/dl)	73.4 (33.8)	76.8 (48.0)	76.9 (34.9)	87.5 (44.2)	<0.001
HDL-C (mg/dl)	66.6 (14.5)	66.2 (14.0)	66.7 (14.9)	64.9 (14.9)	0.095
LDL-C (mg/dl)	102.2 (24.4)	105.4 (26.7)	107.3 (26.7)	115.1 (30.2)	<0.001
Uric acid (mg/dl)	4.18 (0.91)	4.18 (0.83)	4.24 (0.85)	4.25 (0.87)	0.263
hsCRP (mg/l)	0.07 (0.20)	0.07 (0.17)	0.07 (0.21)	0.10 (0.36)	0.105
Insulin (IU/ml)	5.12 (3.50)	5.13 (2.92)	5.03 (2.93)	5.41 (3.32)	0.135
HOMA-IR	1.14 (0.93)	1.14 (0.71)	1.12 (0.72)	1.24 (0.83)	0.036
BMI (kg/m^2)	21.53 (3.06)	21.39 (2.78)	21.38 (2.95)	21.90 (3.10)	0.003
Waist (cm)	74.24 (7.87)	74.46 (7.73)	74.60 (7.86)	75.84 (7.98)	<0.001
Systolic BP (mmHg)	95.9 (8.2)	97.7 (8.5)	100.3 (8.9)	107.0 (10.7)	<0.001
Diastolic BP (mmHg)	61.1 (6.5)	62.8 (6.7)	64.9 (7.0)	69.4 (8.0)	<0.001
Education level					<0.001
≥College graduate	546 (81.49)	520 (78.31)	545 (81.22)	481 (71.26)	
≤High school	104 (15.52)	115 (17.32)	98 (14.61)	163 (24.15)	

Unknown	20 (2.99)	29 (4.37)	28 (4.17)	31 (4.59)	
Smoking status					0.001
Never / former smoker	648 (96.72)	636 (95.78)	627 (93.44)	620 (91.85)	
Current smoker	15 (2.24)	15 (2.26)	17 (2.53)	25 (3.70)	
Unknown	7 (1.04)	13 (1.96)	27 (4.02)	30 (4.44)	
Alcohol (g/day)	3.0 (1.0-7.0)	3.0 (0.0-6.0)	3.0 (1.0-7.0)	3.0 (1.0-7.0)	0.572
Vigorous exercise frequency					0.877
<1 time/week	504 (75.22)	511 (76.96)	504 (75.11)	503 (74.52)	
≥1 time/week	160 (23.88)	145 (21.84)	162 (24.14)	164 (24.30)	
Unknown	6 (0.90)	8 (1.20)	5 (0.75)	8 (1.19)	

Data are presented as n (%) or mean±SD or median (IQR).

Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg.

HbA1c, hemoglobin A1c; ALT, alanine aminotransferase; AST, Aspartate Aminortansferase; GGT, gamma glutamyl transferase; BP, blood pressure; BMI, body mass index; HTN, hypertension; HDL-C, high density lipoprotein cholesterol; HOMA IR, homeostasis model assessment of insulin resistance; LDL-C, low density lipoprotein cholesterol.

Table S6. Risk of Incident HTN According to baPWV in Men and Women.

	Person-years	Events (No.)	Incident rate (10,000 person-years)	Age- adjusted HR (95% CI)	Multivariable-adjusted HR* (95% CI)			
					Model 1	Model 2	Model 3	Model 4
Men								
Q1	7,789.6	106	136.0	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Q2	8,244.8	180	218.3	1.57 (1.24-2.00)	1.68 (1.32-2.14)	1.77 (1.39-2.25)	1.38 (1.08-1.76)	1.29 (1.0-1.64)
Q3	8,424.1	299	354.9	2.54 (2.03-3.17)	2.70 (2.16-3.38)	2.85 (2.28-3.56)	1.98 (1.58-2.48)	1.80 (1.44-2.26)
Q4	8,439.6	468	554.5	3.90 (3.15-4.83)	4.04 (3.26-5.00)	4.19 (3.38-5.19)	2.19 (1.75-2.73)	1.96 (1.57-2.46)
Women								
Q1	1,625.5	1	6.1	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Q2	1,639.8	7	42.6	6.82 (0.84-55.57)	6.69 (0.82-54.63)	7.23 (0.89-59.10)	3.76 (0.45-31.69)	3.03 (0.36-25.92)
Q3	1,635.2	4	24.4	3.64 (0.41-32.74)	3.96 (0.44-35.78)	4.07 (0.45-36.74)	2.01 (0.22-18.48)	1.62 (0.17-15.10)
Q4	1,635.0	30	183.4	26.07 (3.49-194.86)	29.67 (3.94-223.32)	31.34 (4.16-235.94)	5.01 (0.62-40.69)	3.89 (0.47-32.10)

baPWV, brachial-ankle pulse wave velocity; CI, confidence interval; HR, hazard ratio; HTN, hypertension.

Hypertension was defined as systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg.

*Model 1: adjustment for age, medical center, year of screening examination, smoking status, alcohol intake, exercise and educational level; Model 2: Model 1 and adjustment for BMI; Model 3: Model 2 and adjustment for SBP; Model 4: Model 3 and adjustment for DBP.

Table S7. The Incidence Rate of Hypertension According to baPWV Quartile and SBP Quartile in Men and Women.

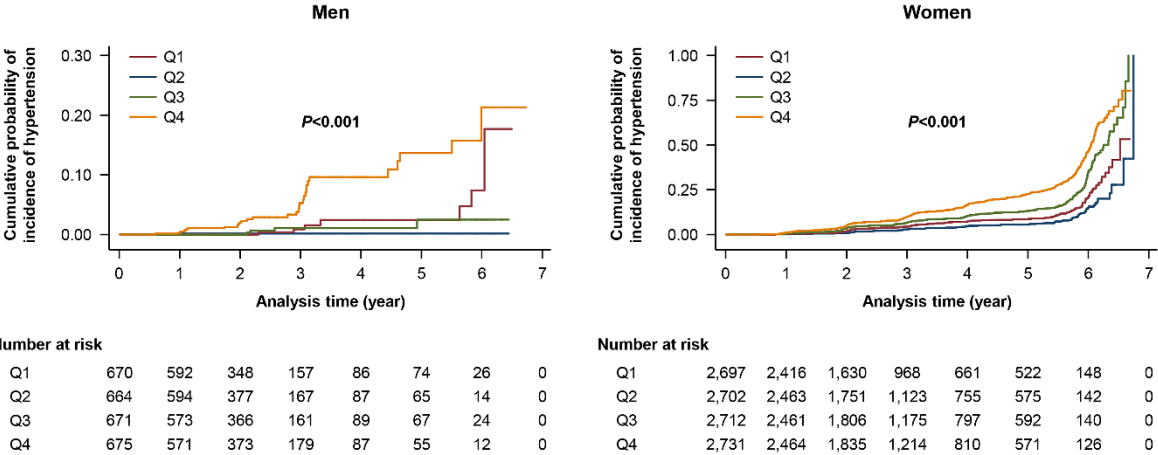|	Incidence rate of hypertension (1,000 person-years)							
	Quartiles of baPWV in Men				Quartiles of baPWV in Women			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Quartiles of baseline SBP (mmHg)								
S1 (70-99)	10.97	18.24	37.68	21.74	0.00	1.12	6.98	4.32
S2 (100-106)	34.49	45.50	50.51	66.26	8.98	16.05	10.07	29.16
S3 (107-112)	62.36	75.99	90.80	120.89	6.97	27.93	25.37	60.00
S4 (112-129)	95.06	112.98	131.60	147.36	0.00	57.84	64.76	102.73

baPWV, brachial-ankle pulse wave velocity; SBP, systolic blood pressure.

Figure S1. Incident hypertension rate by quartiles of baseline systolic blood pressure and dichotomization of baPWV in women.
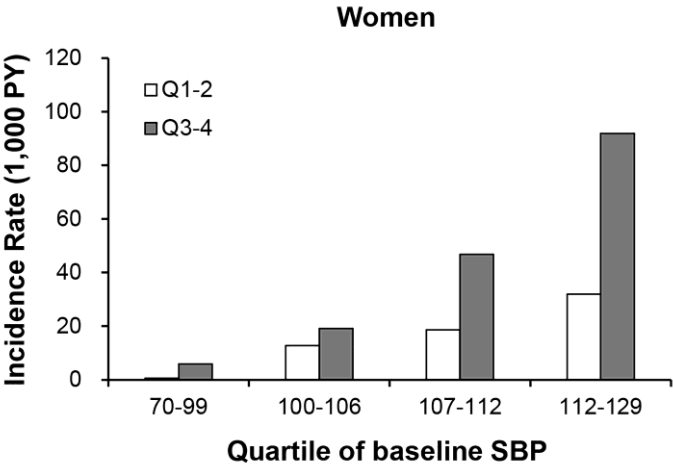
baPWV, brachial-ankle pulse wave velocity.

Figure S2. Kaplan–Meier Curves for incident hypertension according to baPWV in men and women.

Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg.