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Short stature is associated with higher pulse wave velocity in subjects without overt cardiovascular disease

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Abstract

Short stature is reportedly associated with cardiovascular disease (CVD). However, the mechanism underlying this intriguing epidemiological finding is unclear. Pulse wave velocity (PWV), a marker of vascular stiffness, is a predictor of future CVD. Therefore, PWV may be affected by height even before overt CVD occurs. Here, we investigated the association between adult height and PWV in subjects without overt CVD.

A total of 1019 subjects (48 ± 12 years old; 509 men, 21 with diabetes mellitus, 209 with hypertension) without overt CVD were enrolled, all of whom underwent brachial-ankle PWV (baPWV) measurements. The subjects were divided into 3 groups by height. A multiple regression model was used to estimate baPWV values among heights after the adjustment for confounders.

Mean baPWV value was highest in the group with the shortest height for both sexes (both $P < .001$). Bivariate correlation analysis between height and baPWV showed significant correlations in men ($r = -0.131$, $P = .003$) and women ($r = -0.180$, $P < .001$). In the multiple regression analysis with adjustment for identified confounders, group height was a predictor of baPWV (P for trend = .003) in younger men (<50 years old) but not in older men, while group height was correlated with baPWV in older women (≥50 years old, P for trend = .014) but not in younger women.

Height is inversely correlated with baPWV in subjects without overt CVD, especially in younger men and older women. This may explain the historical epidemiological observation of an inverse relationship between height and CVD.

Abbreviations: baPWV = brachial-ankle pulse wave velocity, BMI = body mass index, CVD = cardiovascular disease, PWV = pulse wave velocity.

Keywords: arteriosclerosis, cardiovascular disease, height, pulse wave velocity, risk factor

1. Introduction

The inverse relationship between height and the prevalence of cardiovascular disease (CVD) is supported by a large body of epidemiological evidence.[1–4] Although researchers have attempted to determine the mechanism underlying this interesting phenomenon, no single theory has been proven entirely satisfactory. Risk factors reportedly predict the occurrence of CVD. Given the relationship between height and CVD, short stature may also be correlated with risk factors before overt CVD develops since the occurrence of clinical heart and vessel disease results from sequential pathological processes. Therefore, the determination of a correlation between adult height and specific risk factors for CVD in the subclinical period will enhance our understanding of the correlation between height and CVD, and thus, provide the target of preemptive treatment. Pulse wave velocity (PWV), a marker of arterial stiffening, reportedly correlates with and/or predicts the risk of CVD.[5–11] This study aimed to answer the following questions:

1) does short stature in adults affect PWV, a noninvasive marker of arterial stiffness, in subjects without overt CVD? and
2) in which population subgroup is PWV more affected by height?

2. Methods

2.1. Design and subjects

This cross-sectional study was approved by the Institutional Review Board of Gil Medical Center, Gachon University College of Medicine, which waived the need for written informed consent. All data collection procedures were performed per the ethical standards of the institutional principles and the Declara-

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JM and ICH contributed equally to this work and are the co-first authors.

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Table 1

Subject characteristics by height. Continuous variables were analyzed. Male and female subjects were separately divided into 3 groups by height. Height group was categorized arbitrarily based on the distribution of current samples.

	Male height (cm)				Female height (cm)			
	<165 (n=166)	165–174 (n=236)	≥175 (n=107)	*P* value	<155 (n=112)	155–164 (n=287)	≥165 (n=111)	*P* value
Age, yr	53.3±9.8	47.4±11.7	38.7±10.7	**<.001**	57.4±9.7	49.2±10.1	42.9±10.7	**<.001**
Body mass index, kg/m^2	24.4±3.2	25.0±2.9	25.4±3.4	**.026**	25.0±3.5	23.9±3.4	25.2±3.8	**<.001**
Total cholesterol, mg/dL	203±36	198±33	191±36	**.016**	215±39	201±37	199±39	**.002**
baPWV, m/s	1416±234	1406±246	1306±189	**<.001**	1430±240	1330±224	1311±165	**<.001**

baPWV = brachial-ankle pulse wave velocity.

The *P* values were derived from 1-way analysis of variance or the Chi-squared test.

tion of Helsinki principles (6th revision). Consecutive subjects who visited the cardiology outpatient clinic of our hospital for medical check-up and were not taking any medications were enrolled. Subjects with a medical history of CVD, such as ischemic heart disease, valvular heart disease, symptomatic arrhythmia, or heart failure, were excluded. Subjects who had mild hypertension or diabetes and were not taking any medications were allowed to be enrolled, whereas patients with established renal disease (serum creatinine > 1.4 mg/dL), liver disease (aspartate aminotransferase or alanine aminotransferase level ≥ 3 times the upper limit of normal), or any type of cancer were excluded.

Height and weight were measured to the nearest 0.1 kg and 0.1 cm, respectively, and body mass index (BMI) was calculated. Blood tests were performed after a 12-hour fast. Diabetes was defined as fasting glucose levels ≥ 126 mg/dL, 2-hour postprandial glucose level ≥ 200 mg/dL, glycated hemoglobin (HbA1c) ≥ 6.5%, or a previous diagnosis of the disease. Hypertension was defined as a systolic blood pressure ≥ 140 mm Hg, diastolic blood pressure ≥ 90 mm Hg, or previous diagnosis of this condition. Problematic drinking was defined as the consumption of >14 standard drinks/wk for men and >7 standard drinks/wk for women.

2.2. Measurement of PWV

Brachial-ankle PWV (baPWV) and blood pressure were non-invasively measured using the oscillometric method with a commercially available volume plethysmography device (VP-2000; Nippon Colin Ltd., Komaki, Japan) with the subjects in a supine position after 3 deep breaths and a 5-minute rest in a quiet room. Pulse waves from the brachial and tibial arteries were simultaneously obtained and recorded, and baPWV was calculated using the following formula: (D1 - D2)/T, where D1 is the distance from the suprasternal notch to the ankle, D2 is the distance from the suprasternal notch to the brachium, and T is the time interval between the brachium and ankle. The distances between the sampling points of baPWV were automatically calculated from the subject's height. We used the mean baPWV of the right and left side values for analysis.

2.3. Statistical analysis

All statistical analyses were sex-specific. Descriptive statistics are presented as mean ± standard deviation or percentage. Differences in the characteristics of the study participants by height were evaluated using the Chi-squared test or one-way analysis of variance. Pearson correlation analysis was used to examine the relationship between height and baPWV. We used a stepwise multivariate regression analysis to identify the factors associated with baPWV. Finally, we estimated baPWV values from the heights adjusted for potential confounders from the above process. All analyses were performed using STATA statistical software version SE 9.2 (Stata Corp., College Station, TX). All statistical tests were 2-sided, and results with values of $P < .05$ were considered statistically significant.

3. Results

The clinical characteristics by height tertile group in both sexes are shown in Table 1 (continuous variables) and Table 2 (categorical variables). Among the male subjects, the first tertile group had a relatively higher age and lower BMI. Total cholesterol level was also associated with height group. It was noteworthy that baPWV was significantly higher in the first tertile group and lower in the third tertile group (Table 1). Among the female subjects, the first tertile group was the oldest, while the second tertile group had the lowest BMI. Total cholesterol level was also highest in the first tertile group. In this group, baPWV also had an inverse correlation with the height tertile group (Table 1). Bivariate correlation analysis revealed a significant inverse correlation between baPWV and height in male and female subjects (Fig. 1). Smoking and alcohol histories differed among height groups of male and female subjects (Table 2). On the other hand, prevalence of hypertension and diabetes mellitus did not differ among height groups.

We sought to determine estimated baPWV values across the height tertile groups. For that purpose, we needed to identify determinants of baPWV other than height. A stepwise multivariate regression model was used to identify factors other than height that are correlated with baPWV (Table 3); we did not include height in the model due to the multicollinearity of height with BMI, which is calculated from height. In male subjects, older age (≥50 years; here, 50 years was the median age of the study subjects), problematic drinking, and hypertension were independently associated with baPWV. In female subjects, older age (≥50 years), overweight status (BMI≥25 kg/m^2), and history of hypertension were independent predictors of baPWV. Based on the results, we further divided the study subjects into 4 age-/sex-based subgroups and sought to determine estimated baPWV values with the adjustment for identified confounders including a history of hypertension and problematic drinking in men (Fig. 2-A) and a history of hypertension and overweight status (BMI≥25 kg/m^2) in women (Fig. 2-B). A significant correlation was found between baPWV and height only in younger subjects in the male group (Fig. 2-A). In contrast, a significant inverse correlation was

Table 2

Subject characteristics by height. Categorical variables were analyzed. Male and female subjects were separately divided into 3 groups by height. Height was categorized arbitrarily based on the distribution of current samples.

	Male height (cm)				Female height (cm)			
	<165	165–174	≥175	*P* value	<155	155–164	≥165	*P* value
Subject numbers, n (%)	166 (100)	236 (100)	107 (100)		112 (100)	287 (100)	111 (100)	
Subjects by age group				**<.001**				**<.001**
20–39 yr, n (%)	14 (8.4)	54 (22.9)	63 (58.9)		4 (3.6)	46 (16.0)	39 (35.1)	
40–59 yr, n (%)	109 (65.7)	148 (62.7)	39 (36.5)		57 (50.9)	200 (69.7)	69 (62.2)	
≥60 yr, n (%)	43 (25.9)	34 (14.4)	5 (4.7)		51 (45.5)	41 (14.3)	3 (2.7)	
Subjects by body mass index group	**.007**	**007**						
<23 kg/m^2, n (%)	59 (35.5)	59 (25.0)	27 (25.2)		33 (29.5)	123 (42.9)	31 (27.9)	
23–24.9 kg/m^2, n (%)	46 (27.7)	54 (22.9)	19 (17.8)		29 (25.9)	70 (24.4)	23 (20.7)	
≥25 kg/m^2, n (%)	61 (36.8)	123 (52.1)	61 (57.0)		50 (44.6)	94 (32.8)	57 (51.4)	
Subjects by smoking group			**<.001**				**<.001**	
Never, n (%)	108 (65.1)	54 (22.9)	27 (25.2)		107 (95.5)	256 (89.8)	46 (41.8)	
Ex-, n (%)	34 (20.5)	112 (47.5)	58 (54.2)		3 (2.7)	23 (8.1)	41 (37.3)	
Current, n (%)	24 (14.5)	70 (30.0)	22 (20.6)		2 (1.8)	6 (2.1)	23 (20.9)	
Subjects by drinking group			**<.001**				**<.001**	
None, n (%)	86 (51.8)	73 (30.9)	25 (23.8)		86 (78.2)	183 (64.0)	33 (30.0)	
Social, n (%)	65 (39.2)	98 (41.5)	50 (47.6)		22 (20.0)	91 (31.8)	74 (67.3)	
Risky, n (%)	15 (9.0)	65 (27.5)	30 (28.6)		2 (1.8)	12 (4.2)	3 (2.7)	
Subjects by comorbidity group								
Hypertension, n (%)	34 (20.5)	64 (27.1)	22 (20.6)	.216	20 (17.9)	46 (16.1)	23 (20.7)	.557
Type 2 diabetes, n (%)	5 (3.0)	5 (2.1)	1 (0.9)	.514	3 (2.7)	4 (1.4)	3 (2.7)	.581
Subjects by total cholesterol level group	.094	**.011**						
<200 mg/dL, n (%)	77 (46.4)	124 (52.5)	67 (62.6)		38 (33.9)	146 (50.9)	57 (51.4)	
200–239 mg/dL, n (%)	63 (38.0)	83 (35.2)	26 (24.3)		45 (40.2)	95 (33.1)	40 (36.0)	
≥240 mg/dL, n (%)	26 (15.7)	29 (12.3)	14 (13.1)		29 (25.9)	46 (16.0)	14 (12.6)	

baPWV = brachial-ankle pulse wave velocity.

The *P* values were derived from 1-way analysis of variance or the Chi-squared test.

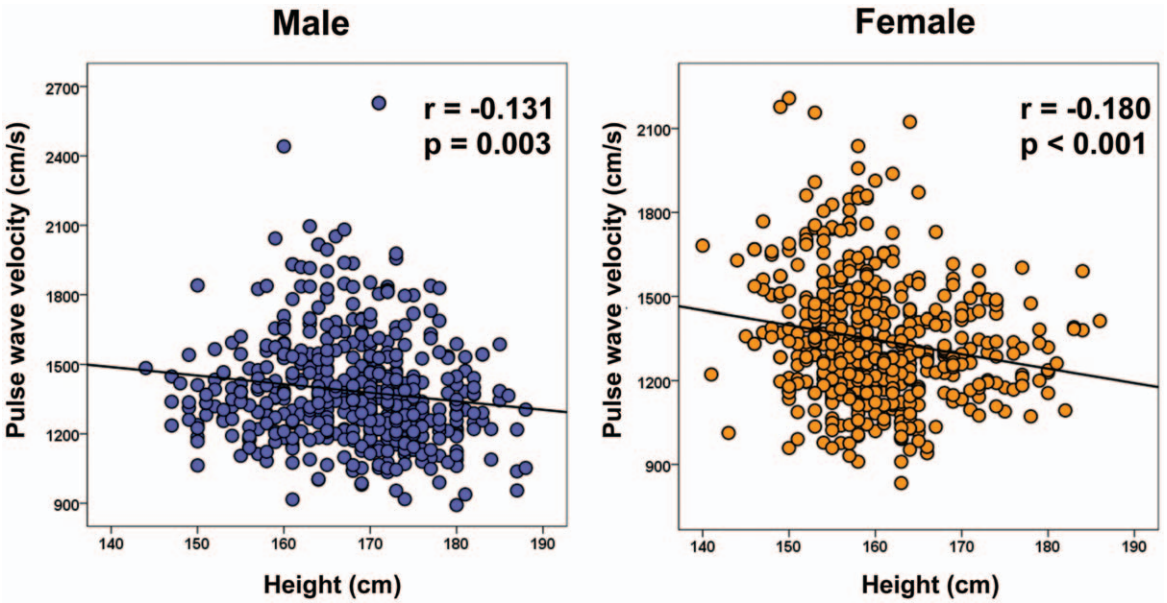

Figure 1. Bivariate correlation between height and brachial-ankle pulse wave velocity in the male and female groups. A significant inverse correlation is seen between brachial-ankle pulse wave velocity and height in male and female subjects.

Table 3

Factors associated with pulse wave velocity from the stepwise multivariate regression models. Height was not included in the model due to the multicollinearity of height with body mass index which is calculated from height. Based on these results, we further divided the study subjects into 4 age-/sex-based subgroups and sought to determine estimated brachial-ankle pulse wave velocity values with the adjustment for identified confounders including a history of hypertension and problematic drinking in men (Fig. 2-A) and a history of hypertension and overweight status (body mass index≥25 kg/m^2) in women (Fig. 2-B).

	Male		Female	
	β (95% CI)	*P* value	β (95% CI)	*P* value
≥50 yr	157 (120–195)	<.001	162 (127–196)	<.001
Overweight (BMI≥25 kg/m^2)	—		46 (10–82)	.012
Current smoking	—		—	
Problematic drinking	53 (8–99)	.022	—	
Hypertension	148 (104–193)	<.001	140 (94–185)	<.001
Diabetes	—		—	
Hypercholesterolemia	—		—	

BMI = body mass index, CI = confidence interval.
The median age of the current sample was 50 years.

found between baPWV and height only in older subjects in the female group (Fig. 2-B).

4. Discussion

4.1. Main findings

In this study, we found that baPWV was higher in the shorter group of subjects without a history of overt CVD. An inverse linear correlation, albeit weak, was found between height and baPWV in both sexes (Fig. 1). This finding helps explain the historic epidemiological finding of a relationship between short stature and CVD; the impaired vascular compliance in shorter individuals serves, at least partially, as a link between short stature and the future occurrence of CVD. As adult height cannot be changed, the identification of modifiable connectors between short stature and CVD that can be targets of preemptive treatment before overt CVD ensues is important.

PWV is known to be influenced by many factors, including the following:

1) sex is an important determinant of PWV, presumably because of the protective effect of estrogen and/or sex-dependent health-related habits such as smoking, drinking, or a lack of exercise[12,13]) age is known to affect PWV by inducing structural or functional vascular abnormalities.[14] Therefore, we divided our subjects into 4 groups by sex and median age (50 years in this cohort). The correlation between height and baPWV was independent and statistically significant, particularly in the younger (<50 years) male (Fig. 2-A) and older (≥50 years) female subjects (Fig. 2-B).

4.2. Short stature is associated with high prevalence and worse outcomes of CVD: is a higher PWV a potential link?

The inverse relationship between height and CVD was observed in many epidemiological studies; however, the reason why short stature affects CVD risk remains largely unknown. The etiology of CVD is generally multifactorial, and the occurrence of CVD is a continuum of pathophysiological processes. PWV is a suggested early marker of arteriosclerosis and, therefore, a predictor of CVD in the general population or in patient groups with clinical conditions such as hypertension, diabetes mellitus, end-stage renal disease, small or large cerebral vessel disease, and coronary artery disease.[5–11] Our data suggest that PWV is a potential link between short stature and CVD.

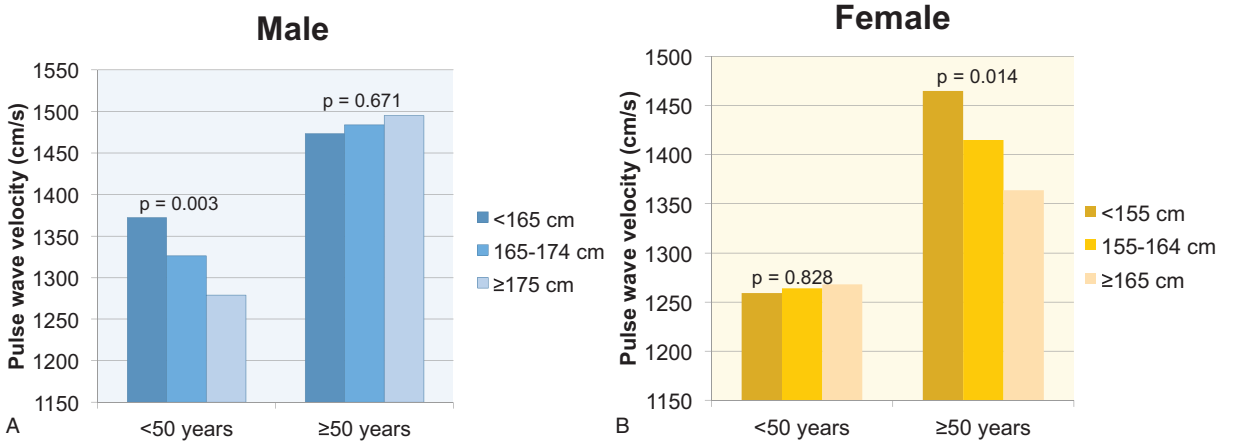

Figure 2. Estimated pulse wave velocity across the height tertile groups. A. Adjusted for a history of hypertension and problematic drinking in men. B. Adjusted for a history of hypertension and overweight status (body mass index≥25 kg/m^2) in women.

The mechanisms linking arterial stiffness and atherosclerosis remain unclear. Proposed hypotheses include the following:

1) arterial stiffening leads to hypertensive vascular remodeling[15];
2) high luminal pressure and shear stress accelerate atheroma formation and stimulate excessive vascular collagen deposition, which leads to the progression of atherosclerosis[16];
3) increased pulse pressure is associated with the development and later rupture of plaques[17]; and
4) arteriosclerosis serves as a hemodynamic burden on the left ventricle because earlier reflection waves from peripheral resistance arteries to the ascending aorta close the aortic valve early, leading to ventricular hypertrophy and lower diastolic blood pressure, which reduces coronary perfusion.[18,19] We and our colleagues have also previously reported the association between short stature and the occurrence and outcomes of CVD due to the more advanced diastolic function of shorter patients.[20,21]

4.3. Hypotheses of high PWV in shorter subjects

How can the inverse correlation between height and PWV be explained? 1 possible explanation is presented below. The time of return of reflection wave is relatively shorter in shorter individuals; thus, the pulse pressure and augmentation index are relatively higher.[22] Therefore, arterial stiffening may result from the hemodynamic stress in shorter people. Another hypothesis of ours is that the aortic diameter of a tall subject must be greater than that of a short subject (imagine the size difference between the aortas of a whale and a mouse), and a large population-based study supports this view.[23] In comparisons of the cross-sectional areas of small and large vessels, the difference between their inner diameters is squared; that is, if the internal diameter of a pipe increases by 2 fold, the cross-sectional area, providing that it is a perfect circle, increases by 4 fold. Hence, the larger vessel can convey more blood at any given time provided that the heart-generated pressure allowing the blood to flow is identical. Therefore, the blood flows more slowly in the larger vessel if the cardiac output is the same. In addition, if the texture and stiffness of any given vascular wall are identical, the larger artery can endure greater dilation than the smaller one in terms of the absolute increase in the inner diameter as it is proportionally more compliant. This hypothesis is in line with that of previous studies by Mitchell et al,[24,25] who reported an inverse correlation between aortic diameter and pulse pressure. Although the aims of their studies differed from our study purpose, the main concept of their research, which is characteristic impedance representing the pressure-flow relationship in the aorta inversely correlates with aortic diameter, shares a similar theoretical base with our hypothesis and can explain our study findings. Unfortunately, we do not have aorta size data for our cohort; therefore, we cannot prove our hypothesis at this stage. Further studies are needed to further elucidate this concept.

4.4. Sex and age differences in the PWV-height correlation

The correlation between height and PWV was more remarkable in younger men and older women (Fig. 2-A, 2-B), possibly for the following reasons:

1) confounding factors affecting PWV, such as age, presence of comorbidities, and the cumulative effect of smoking, are less profound in younger men. Therefore, the influence of height is more prominent in younger men than in older men; and
2) the vascular protective effect of estrogen may make the effect of short stature on PWV less remarkable in younger women than in older women, who have experienced menopause. In fact, pulse pressure widening after midlife is particularly more remarkable in women and potentially results from increased stroke volume and/or decreased vascular compliance.[26,27] Our study results imply that the influence of height on arterial stiffness and the future occurrence of CVD may differ across age and/or sex groups.

4.5. Limitations

This study included Korean subjects without overt CVD. Therefore, our results cannot be directly applied to other populations. However, the homogeneity of our study sample (i.e., subjects without CVD from the same ethnic group) can also be considered a strength because height is influenced by race and socioeconomic status. Our main hypothesis to explain our results relates to aortic properties and size; however, we have no data on characteristics such as aortic diameter and wall thickness or stiffness. Further studies are needed to prove this hypothesis. Some investigators also recognized the inverse association between PWV and height, which Liu et al[28] claimed was spurious because the formula used to determine the travel distance of pulse wave is essentially height-dependent and, thus, inadequate. They suggested that PWV should be standardized to height, which seems reasonable. It would be more meaningful if the inverse correlation between height and baPWV was proven in a height-adjusted PWV assessment model.

5. Conclusion

Short stature is associated with a higher baPWV in subjects without overt CVD, a phenomenon that was more prominent in younger men and older women. The relatively greater impairment of vascular compliance in the shorter subjects may at least partially explain the historic epidemiological observation of a correlation between short stature and CVD.

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Author contributions

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References

[1] Njolstad I, Arnesen E, Lund-Larsen PG. Body height, cardiovascular risk factors, and risk of stroke in middle-aged men and women. A 14-year follow-up of the Finnmark Study. Circulation 1996;94: 2877–82.
[2] Wannamethee SG, Shaper AG, Whincup PH, et al. Adult height, stroke, and coronary heart disease. Am J Epidemiol 1998;148:1069–76.
[3] Nelson CP, Hamby SE, Saleheen D, et al. Genetically determined height and coronary artery disease. N Engl J Med 2015;372:1608–18.
[4] Park CS, Choi EK, Han KD, et al. Association between adult height, myocardial infarction, heart failure, stroke and death: a Korean nationwide population-based study. Int J Epidemiol 2018;47: 289–98.

[5] Zhong Q, Hu MJ, Cui YJ, et al. Carotid-femoral pulse wave velocity in the prediction of cardiovascular events and mortality: an updated systematic review and meta-analysis. Angiology 2018;69:617–29.
[6] van Sloten TT, Sedaghat S, Laurent S, et al. Carotid stiffness is associated with incident stroke: a systematic review and individual participant data meta-analysis. J Am Coll Cardiol 2015;66:2116–25.
[7] Kim YB, Park KY, Chung PW, et al. Brachial-ankle pulse wave velocity is associated with both acute and chronic cerebral small vessel disease. Atherosclerosis 2016;245:54–9.
[8] Kim J, Cha MJ, Lee DH, et al. The association between cerebral atherosclerosis and arterial stiffness in acute ischemic stroke. Atherosclerosis 2011;219:887–91.
[9] Lee JY, Ryu S, Lee SH, et al. Association between brachial-ankle pulse wave velocity and progression of coronary artery calcium: a prospective cohort study. Cardiovasc Diabetol 2015;14:147.
[10] Cainzos-Achirica M, Rampal S, Chang Y, et al. Brachial-ankle pulse wave velocity is associated with coronary calcium in young and middle-aged asymptomatic adults: the Kangbuk Samsung Health Study. Atherosclerosis 2015;241:350–6.
[11] Vishnu A, Choo J, Wilcox B, et al. Brachial-ankle pulse wave velocity is associated with coronary calcification among 1131 healthy middle-aged men. Int J Cardiol 2015;189:67–72.
[12] Cunha PG, Cotter J, Oliveira P, et al. Pulse wave velocity distribution in a cohort study: from arterial stiffness to early vascular aging. J Hypertens 2015;33:1438–45.
[13] Shaw LJ, Bairey Merz CN, Pepine CJ, et al. Insights from the NHLBI-Sponsored Women's Ischemia Syndrome Evaluation (WISE) Study: part I: gender differences in traditional and novel risk factors, symptom evaluation, and gender-optimized diagnostic strategies. J Am Coll Cardiol 2006;47:S4–20.
[14] Mattace-Raso F, Hofman A, Verwoert GC, et al. Determinants of pulse wave velocity in healthy people and in the presence of cardiovascular risk factors: 'establishing normal and reference values'. Eur Heart J 2010;31:2338–50.
[15] Dao HH, Essalihi R, Bouvet C, et al. Evolution and modulation of age-related medial elastocalcinosis: impact on large artery stiffness and isolated systolic hypertension. Cardiovasc Res 2005;66:307–17.
[16] Zieman SJ, Melenovsky V, Kass DA. Mechanisms, pathophysiology, and therapy of arterial stiffness. Arterioscler Thromb Vasc Biol 2005;25:932–43.
[17] Witteman JC, Grobbee DE, Valkenburg HA, et al. J-shaped relation between change in diastolic blood pressure and progression of aortic atherosclerosis. Lancet 1994;343:504–7.
[18] Dart AM, Kingwell BA. Pulse pressure–a review of mechanisms and clinical relevance. J Am Coll Cardiol 2001;37:975–84.
[19] Leung MC, Meredith IT, Cameron JD. Aortic stiffness affects the coronary blood flow response to percutaneous coronary intervention. Am J Physiol Heart Circ Physiol 2006;290:H624–30.
[20] Moon J, Lee HJ, Kim YJ, et al. Short stature and ischemic stroke in nonvalvular atrial fibrillation: new insight into the old observation. Int J Cardiol 2014;174:541–4.
[21] Moon J, Suh J, Oh PC, et al. Relation of stature to outcomes in Korean patients undergoing primary percutaneous coronary intervention for acute ST-elevation myocardial infarction (from the INTERSTELLAR Registry). Am J Cardiol 2016;118:177–82.
[22] McGrath BP, Liang YL, Kotsopoulos D, et al. Impact of physical and physiological factors on arterial function. Clin Exp Pharmacol Physiol 2001;28:1104–7.
[23] Vasan RS, Larson MG, Levy D. Determinants of echocardiographic aortic root size. The Framingham Heart Study. Circulation 1995;91:734–40.
[24] Mitchell GF, Lacourciere Y, Ouellet JP, et al. Determinants of elevated pulse pressure in middle-aged and older subjects with uncomplicated systolic hypertension: the role of proximal aortic diameter and the aortic pressure-flow relationship. Circulation 2003;108:1592–8.
[25] Mitchell GF, Conlin PR, Dunlap ME, et al. Aortic diameter, wall stiffness, and wave reflection in systolic hypertension. Hypertension 2008;51:105–11.
[26] Mitchell GF. Rising pressure pulsatility after midlife in women. Hypertension 2019;73:980–2.
[27] Li Y, Jiang B, Keehn L, et al. Hemodynamic mechanism of the age-related increase in pulse pressure in women. Hypertension 2019;73:1018–24.
[28] Liu YP, Richart T, Li Y, et al. Is arterial stiffness related to body height? Hypertension 2010;55:e24–5.