Journal of Human Hypertension (2011) 25, 152–158

www.nature.com/jhh

ORIGINAL ARTICLE

Arterial stiffness and left-ventricular diastolic dysfunction: Guangzhou Biobank Cohort Study-CVD

L Xu[1,2], CQ Jiang[2], TH Lam[1], XJ Yue[2], JM Lin[2], KK Cheng[3], B Liu[2], Y Li Jin[2], WS Zhang[2] and GN Thomas[3]

[1]*Department of Community Medicine, School of Public Health, University of Hong Kong, Hong Kong, PR China;* [2]*Guangzhou No.12 Hospital, Guangzhou, PR China and* [3]*Public Health, Epidemiology, and Biostatistics, University of Birmingham, Birmingham, UK*

Brachial–ankle pulse wave velocity (baPWV), a marker of arterial stiffness, is an established cardiovascular risk factor of ventricular stiffening. We studied the association of baPWV with left-ventricular (LV) diastolic function in a sub-study of the Guangzhou Biobank Cohort Study. In all, 378 Chinese subjects with a normal ejection fraction (>50%) had baPWV measurement by a noninvasive automatic waveform analyser, carotid intima-medial thickness (IMT) measurement by B-mode ultrasonography and cardiac diastolic function assessment by echocardiography. After adjusting for age, both baPWV and IMT were associated with LV mass index, posterior wall end-diastolic thickness and inter-ventricular end-diastolic thickness, but only baPWV was associated with deceleration time, atrial flow velocity and *E/A* ratio. Multivariable linear regression model showed that baPWV and mean arterial pressure, but not IMT, were significantly associated with *E/A* ratio ($\beta = -0.02$, $P = 0.03$ and $\beta = -0.36$, $P = 0.02$, respectively). The receiver operator characteristic curve showed that baPWV was better than pulse pressure or mean arterial pressure to detect LV diastolic dysfunction (*E/A* < 1.0). Our study suggested that increased baPWV might be an independent risk factor or marker for diastolic dysfunction. Early detection of an intervention on increased baPWV may be important for prevention of cardiac diastolic dysfunction.
Journal of Human Hypertension (2011) **25,** 152–158; doi:10.1038/jhh.2010.44; published online 29 April 2010

Keywords: arterial stiffness; diastolic dysfunction; brachial–ankle pulse wave velocity

Introduction

Pulse wave velocity (PWV) has been reported as a marker of arterial stiffness and widely used in clinical and population-based epidemiological studies.[1,2] Brachial–ankle PWV (baPWV) obtained by a noninvasive method using oscillometric technique has been shown to be strongly correlated with increased cardiovascular events[3] and be more representative than the traditional invasively derived carotid femoral PWV.[4]

Left-ventricular (LV) diastolic dysfunction is the most common cardiac abnormality associated with hypertension and is a predictor of cardiovascular disease[5] and all-cause mortality.[6] A European study on 1274 community-based volunteers showed that 2.8% of the subjects aged 25–35 years and 15.8% aged 65 years or above had LV diastolic dysfunction, and the prevalence of diastolic dysfunction was higher than that of systolic dysfunction and increased in the elderly.[7] A more recent study in Canberra showed that the prevalence of diastolic dysfunction was 34.7% in 1275 randomly selected residents of Canberra aged 60–86 years.[8] Both of these studies showed that diastolic dysfunction is common in older populations and often unaccompanied by overt congestive heart failure.[7,8]

Emerging data have shown that PWV is associated with ultrasonographically detected LV diastolic dysfunction clinically and epidemiologically.[9,10] Although arterial stiffness as measured by baPWV was associated with atherosclerosis and diastolic heart failure in patients with hypertension,[9] it is less clear whether an increased baPWV relates to the LV diastolic dysfunction in the general population. Furthermore, the association between carotid intima-medial thickness (IMT), which is an established marker of atherosclerosis, and LV diastolic dysfunction has not been reported.

The present cross-sectional study examined the association between electrocardiographically determined LV diastolic dysfunction and baPWV or carotid IMT in a community-based sample.

Correspondence: Professor TH Lam, Department of Community Medicine, School of Public Health, The University of Hong Kong, School of Public Health, 21 Sassoon Road, Hong Kong, PR China. E-mail: hrmrlth@hkucc.hku.hk
Received 23 November 2009; revised 23 February 2010; accepted 27 February 2010; published online 29 April 2010

Methods

Subjects

The Guangzhou Biobank Cohort Study is a collaborative study of Guangzhou 12th People's Hospital, China, the University of Hong Kong and the University of Birmingham, UK. Subjects are recruited from 'The Guangzhou Health and Happiness Association for the Respectable Elders' (GHHARE), which is a community social and welfare association aligned with the municipal government. Membership is open to older adults for a monthly fee of about 4 RMB (50 US cents). About 7% of Guangzhou permanent residents aged 50 years or above are members of this association. We have recruited over 30 000 older people from September 2003 to December 2007. Details of participant recruitment and methods in the Guangzhou Biobank Cohort Study have been reported earlier.[11]

We only included those who were ambulatory and not receiving treatment for life threatening diseases, such as cancer. In a more detailed sub-study on cardiovascular disease, 378 subjects who had a normal ejection fraction (EF > 50%) were included in this study from a random sample of 1996 during the Phase 3 of the Guangzhou Biobank Cohort Study (November 2006–September 2007).[12] The study has received ethical approval from the Guangzhou Medical Ethics Committee of the Chinese Medical Association, Guangzhou, China. All participants gave written, informed consent before participating in the study.

Demographic and laboratory parameters

A standardized questionnaire was used to assess personal disease history and lifestyle, including smoking status and physical activity according to the International Physical Activity Questionnaire.[13] The reliability of the questionnaire was tested in 200 subjects with κ values of 0.88 and 0.96 for the two questions about smoking status.[14] Resting seated blood pressure was measured three times using an automated sphygmomanometer (Omron 705CP, Tokyo, Japan), which had been previously validated by comparison with the manual mercury sphygmomanometer,[15] and the last two measurements were averaged for analysis. Mean arterial pressure was defined as (systolic blood pressure + diastolic blood pressure *2)/3. Pulse pressure was defined as systolic blood pressure − diastolic blood pressure. Height and weight were measured using standardized procedure that had been described elsewhere[12] and body mass index was assessed. Fasting parameters including plasma glucose and lipids (triglycerides, total, low-density lipoprotein- and high-density lipoprotein-cholesterol) were measured in the Clinical Laboratory of the Guangzhou Number 12 Hospital using standardized procedures.

Intima-medial thickness

Carotid B-mode colour ultrasonographic examination was performed using ALT HDI 3000 mainframe enhanced, linear array scanner (medium frequency, 7.5 MHz) by a specialist physician. The operators were registered ultrasound doctors who had a professional certificate for colour Doppler ultrasound measurement awarded by the Ministry of Health of China. All scans were performed following a predetermined, standardized scanning protocol for the right and left carotid arteries using images of the far wall of the distal 10 mm of the common carotid arteries. Three scanning angles, with the image focused on the posterior wall, were recorded from the angle showing the greatest distance between the lumen–intima interface and the media–adventitia interface. Carotid IMT measurements were performed off-line with the use of automated image analysis software. Details on the procedure used in this study and its reproducibility have been published elsewhere.[12]

Brachial–ankle PWV

Subjects had baPWV measurement in the supine position after 5 min of bed rest using an automatic waveform analyser (BP-203RPE; Colin Medical Technology, Komaki, Japan). This device stored data of the waveforms of both brachium and ankles for a sampling time. The time interval between the wave front of the brachial waveforms and that of the waveforms of ankle was automatically measured, which was defined as *T*. The path lengths from the suprasternal notch to the elbow (La) and also from the suprasternal notch to the ankle (Lb) were automatically calculated based on the patient's height. Then, baPWV was calculated using the following equation: baPWV ($cm\,s^{-1}$) = (Lb − La)/*T*, and the averaged left and right baPWV were obtained for the data analysis.

Diastolic function parameters

M-mode echocardiograms were obtained as guided by two-dimensional echocardiography using an echocardiographic instrument (General Electric Vivid 7, Milwaukee, WI, USA) equipped with a transducer having a frequency range of 2.5–3.5 MHz. All scans performed following a standardized scanning protocol were recorded for off-line analysis. To reduce inter-observer variability, all scans were analysed by a single experienced physician. The LV mass (LVM) was calculated by Devereux's method.[16] The LVM index (LVMI) was calculated as the LVM divided by the body surface area. The LV ejection fraction (LVEF was derived automatically from the equipment. The peak velocity of early trans-mitral flow (*E* velocity) and the peak velocity of atrial flow (*A* velocity) were recorded. *E*/*A* was the ratio of *E* velocity to *A* velocity. The deceleration time was the interval from the *E*-wave peak to the decline of the velocity to baseline. Isovolumic relaxation time was determined as the interval between the end of

ejection and the onset of LV filling. An *E*/*A* ratio of $\leqslant 1.0$ was considered as indicating of diastolic dysfunction.[17] All subjects had a normal LVEF (EF > 50%) and no subject in this study had a pseudonormal diastolic function (*E*/*A* ratio of 1.0 to 1.5 and deceleration time > 240 ms).[17] The physicians who performed the assessments above were blinded to other information.

Statistical analyses

All data analysis was conducted using Stata/IC 10.1. Statistical significance was set at a two-tailed $P<0.05$. Analysis of covariance was used for continuous variables with adjustment of age. Multiple linear regression analysis was applied to evaluate whether the relationship between *E*/*A* ratio and baPWV or carotid IMT is independent from other cardiovascular risk factors. Stepwise forward regression models were used to select significant predictors of *E*/*A* ratio. Receiver operating characteristic curve was used to compare baPWV, pulse pressure and mean arterial blood pressure in discriminating subjects with LV diastolic dysfunction (*E*/*A* ratio of <1.0).

Results

Subject characteristics

The mean (s.d.) age of the 378 subjects were 59.1 (6.1) years; 57.9% were men and 13.0% had an educational level of college or above. Most of them were physically active (70.3%) and did not smoke (18.7% current smokers); 8.0% had type 2 diabetes; 31.8% had hypertension; and only two third of the hypertensive subjects had blood pressure lowering medication (Table 1).

Table 2 shows that low *E*/*A* ($\leqslant 1.0$) was significantly associated with increasing age, mean arterial stiffness, pulse pressure, carotid IMT, baPWV, hypertension and medication for hypertension (*P* from 0.03 to <0.001).

Impact of PWV and IMT on indices of LV diastolic function

Table 3 shows that after adjusting for age, increased baPWV was significantly associated with increased peak velocity of *A*-wave and LVM, LVMI, posterior wall end-diastolic thickness and inter-ventricular end-diastolic septal thickness, and decreased *E*/*A* ratio (*P* from 0.02 to <0.001). Significant association was also found in carotid IMT with LVM, LVMI, posterior wall end-diastolic thickness and inter-ventricular end-diastolic septal thickness (*P* from 0.02 to <0.001).

Predictors of E/A ratio

Table 4 shows that, in multivariable linear regression models with forced entry of age and baPWV or IMT using stepwise forward selection, baPWV, but not carotid IMT, was a significant predictor for LV diastolic dysfunction, with an increase in 1.0 m s^{-1} baPWV associated with a decrease in 0.02 *E*/*A* ($P=0.03$).

Table 1 Demographic characteristics and biochemical parameters in 378 subjects with normal ejection fraction

Number of subjects	378
Age (years)	59.1 ± 6.1
Sex (% men)	57.9
Education (% college or above)	13.0
Physical activity (% physically active)	70.3
Smoking (% current)	18.7
Height (cm)	161.6 ± 7.8
Body mass index (kg m^{-2})	23.5 ± 2.7
LDL-cholesterol (mmol l^{-1})	3.42 ± 0.65
HDL-cholesterol (mmol l^{-1})	1.54 ± 0.36
Total cholesterol (mmol l^{-1})	5.65 ± 0.99
Fasting plasma glucose (mmol l^{-1})	5.26 ± 0.80
Mean arterial pressure (mm Hg)	98 ± 15
Pulse pressure (mm Hg)	50 ± 12
Carotid intima-medial thickness (mm)	0.73 ± 0.15
Brachial–ankle pulse wave velocity (m s^{-1})	15.1 ± 2.7
E/*A* ratio	1.04 ± 0.33
Diabetes (%)	8.0
Hypertension (%)	31.8
Medication for hypertension (%)	20.2

Abbreviations: HDL, high-density lipoprotein; LDL, low-density lipoprotein.
Mean ± s.d. or %.

We also performed a multivariable regression analysis for the association between baPWV/IMT and *E*/*A* ratio, adjusting for age, sex, high-density lipoprotein- and low-density lipoprotein-cholesterol, body mass index, height, fasting plasma glucose, mean arterial pressure, education, smoking and medication for hypertension, and the results remained unchanged (regression coefficient = −0.02, $P=0.03$). No association between IMT and *E*/*A* ratio was found (Table not shown).

Figure 1 shows that, compared to pulse pressure and mean arterial pressure, the overall performance (area under curve (AUC)) of baPWV was superior in detecting LV diastolic dysfunction (*E*/*A*<1.0) ($AUC_{pp}=0.61$ (95% CI 0.55–0.67, $P<0.001$); $AUC_{map}=0.65$ (95% CI 0.59–0.70, $P<0.001$); $AUC_{pwv}=0.69$ (95% CI 0.64–0.74, $P<0.001$).

Discussion

We have shown that baPWV, but not IMT, was significantly associated with LV diastolic function in subjects with a normal EF, independent of other cardiovascular risk factors. Compared to mean arterial blood pressure and pulse pressure, baPWV was a better predictor (cross-sectionally) of diastolic dysfunction, as measured by *E*/*A* ratio. Therefore, baPWV, assessed as a screening tool in this study, was simple, reliable, noninvasive and better then pulse pressure or mean arterial blood pressure for the detection of sub-clinical diastolic dysfunction. The validity of the baPWV has been reported earlier,

Table 2 Demographic characteristics and biochemical parameters by *E/A* ratio in 378 subjects with normal ejection fraction

	E/A ratio		P-*value*
	>1.0	*⩽1.0*	
E/A ratio range	1.01–2.75	0.49–0.99	—
Number of subjects	165	213	—
Age (years)	57.0 ± 5.0	60.7 ± 6.5	<0.001
Sex (% men)	58.2	57.8	0.93
Education (% primary or below)	12.1	30.5	<0.001
Physical activity (% physically active)	67.7	72.4	0.52
Smoking (% current)	22.6	15.7	0.04
Height (cm)	162.3 ± 7.5	161.2 ± 8.0	0.16
Body mass index (kg m^{-2})	23.2 ± 2.7	23.7 ± 2.6	0.05
LDL-cholesterol (mmol l^{-1})	1.54 ± 0.33	1.54 ± 0.38	0.82
HDL-cholesterol (mmol/l)	3.39 ± 0.62	3.45 ± 0.68	0.38
Total cholesterol (mmol l^{-1})	5.56 ± 0.95	5.73 ± 1.03	0.11
Fasting plasma glucose (mmol l^{-1})	5.17 ± 0.83	5.34 ± 0.77	0.05
Mean arterial pressure (mm Hg)	94 ± 15	102 ± 13	<0.001
Pulse pressure (mm Hg)	48 ± 10	52 ± 14	<0.001
Carotid intima-medial thickness (mm)	0.72 ± 0.13	0.75 ± 0.16	0.03
Brachial–ankle pulse wave velocity (m s^{-1})	14.1 ± 2.1	15.9 ± 2.9	<0.001
Diabetes (%)	6.1	9.4	0.24
Hypertension (%)	21.2	40.1	<0.001
Medication for hypertension (%)	11.5	26.9	<0.001

Abbreviations: HDL, high-density lipoprotein; LDL, low-density lipoprotein.
Mean ± s.d. or %. *E/A* ratio, ratio of early trans-mitral flow velocity to atrial flow velocity.

Table 3 Age-adjusted linear regression models of the associations between brachial–ankle pulse wave velocity (PWV) and carotid intima-medial thickness (IMT) with indices of cardiac diastolic function in 378 subjects with normal ejection fraction

	Model predictive of LV function indices with PWV (per m s^{-1})			*Model predictive of LV function indices with carotid IMT (per mm)*	
	β-coefficient (95% CI)	P-*value*		*β-coefficient (95% CI)*	P-*value*
Deceleration time (ms)	−3.47 (−5.84, −1.10)	0.004	Deceleration time (ms)	39.2 (−2.4, 80.7)	0.07
IVRT (ms)	−0.05 (−1.04, 0.93)	0.91	IVRT (ms)	12.2 (−4.9, 29.2)	0.16
Peak *E* (m s^{-1})	−0.06 (−0.01, 0.001)	0.09	Peak *E* (m s^{-1})	−0.09 (−0.2, 0.02)	0.10
Peak *A* (m s^{-1})	0.02 (0.01, 0.03)	<0.001	Peak *A* (m s^{-1})	−0.04 (−0.16, 0.09)	0.57
E/A ratio	−0.03 (−0.05, -0.02)	<0.001	*E/A* ratio	−0.08 (−0.30, 0.14)	0.46
LVM (g)	2.2 (0.34, 4.05)	0.02	LVM (g)	61.0 (29.0, 93.0)	<0.001
LVMI (g m^{-2})	1.1 (0.15, 2.08)	0.02	LVMI (g m^{-2})	23.7 (7.08, 40.4)	0.005
EF (%)	0.17 (−0.13, 0.47)	0.28	EF (%)	0.77 (−4.43, 5.98)	0.77
PWT (mm)	0.10 (0.03, 0.18)	0.004	PWT (mm)	1.82 (0.58, 3.05)	0.004
IVST (mm)	0.11 (0.02, 0.20)	0.02	IVST (mm)	1.84 (0.26, 3.44)	0.02

Abbreviations: CI, confidence interval; EF, ejection fraction; IVRT, isovolumic relaxation time; IVST, inter-ventricular end-diastolic septal thickness; LV, left-ventricular; LVM, left ventricular mass; LVMI, left ventricular mass index; peak *A*, atrial flow velocity; peak *E*, early trans-mitral flow velocity; PWT, posterior wall end-diastolic thickness.

with an inter- and intra-observer coefficient of variation of 8.4 and 10.0%, respectively.[18] To the best of our knowledge, this is the first population-based study in a Chinese community sample showing that baPWV as a simple and noninvasive marker for arterial stiffness was an independent predictor of LV diastolic dysfunction in people with a normal LVEF.

Our finding suggests that arterial stiffness is independently associated with load-dependent alterations in LV diastolic function. Previous studies in both Asia and Western counties have shown a significant association between diastolic dysfunction and arterial stiffness using different markers, such as carotid–femoral PWV, cardio-ankle vascular index and augmentation index.[9,10,19–22] Abhayaratna *et al.*[10,20] showed that among older people in Australia, increased arterial stiffness was associated with severe LV diastolic dysfunction, and the strength of the association varied according to the specific measure, with PWV appeared to be superior to central or brachial pulse pressure for the detection of diastolic dysfunction. As most of the studies above were based on cross-sectional data, whether the association between increased PWV and diastolic dysfunction is causal cannot be determined. However, such association is temporally feasible and biologically plausible. The reflected wave travels more rapidly along the arterial tree in those with arterial stiffness, resulting in an increase in

Table 4 Multivariable linear regression models of the associations between brachial–ankle pulse wave velocity (PWV) and carotid intima-medial thickness (IMT) with *E/A* ratio in 378 subjects with normal ejection fraction

Selected variables	*Model predictive of E/A ratio with baPWV*[a]		*Selected variables*	*Model predictive of E/A ratio with carotid IMT*[a]	
	β-coefficient (95% CI)	P-*value*		*β-coefficient (95% CI)*	P-*value*
Age (per year)	−0.01 (−0.02, −0.007)	<0.001	Age (per year)	−0.02 (−0.02, −0.01)	<0.001
Mean arterial pressure (per 100 mmHg)	−0.36 (−0.66, −0.05)	0.02	Mean arterial pressure (per 100 mm Hg)	−0.56 (−0.78, −0.34)	<0.001
PWV (per m s^{-1})	−0.02 (−0.04, −0.002)	0.03	IMT (per mm)	0.04 (−0.18, 0.27)	0.70

Abbreviation: CI, confidence interval.
[a]Regression models constructed using forced entry of age and baPWV/IMT with stepwise forward selection ($P<0.05$) of the following cardiovascular risk factors: sex, low- and high-density lipoprotein cholesterol, body mass index, height, fasting plasma glucose, mean arterial pressure, education and smoking status and medication for hypertension. Although mean arterial pressure was selected in, the others were not significant and not selected into the final model above.

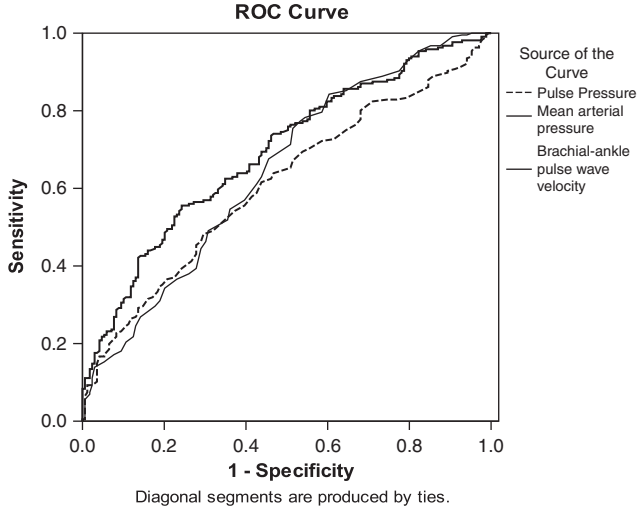

Figure 1 Comparison of overall performances of pulse pressure (pp), mean arterial pressure (map) and brachial–ankle pulse wave velocity (PWV). The areas under the curve (AUC) for detection of left-ventricular diastolic dysfunction (*E/A* ratio<1) were $AUC_{pp}=0.61$ (95% CI 0.55–0.67, $P<0.001$); $AUC_{map}=0.65$ (95% CI 0.59–0.70, $P<0.001$); $AUC_{pwv}=0.69$ (95% CI 0.64–0.74, $P<0.001$).

aortic systolic pressure and a decrease in aortic pressure during diastole.[21] The resultant increase in after-load during LV systole and reduction in coronary perfusion during LV diastole may lead to LV hypertrophy and slowing of LV relaxation.[23]

A population-based study on 1621 older American men and women showed that increased pulse pressure, as an index of arterial stiffening, was associated with increased incidence of congestive heart failure, and thus suggested that pulse pressure was a predictor of congestive heart failure in elderly people.[24] Zile *et al*.[25] reported that objective measurements of LV diastolic function serve to confirm rather than establish the diagnosis of diastolic heart failure. *E/A* ratio is one of the established marker of cardiac diastolic dysfunction,[26] and the changes in *E/A* ratio seem to precede the changes in the deceleration time of mitral inflow in the early stage of cardiac diastolic dysfunction.[6] BaPWV is a more valid marker of arterial stiffness and better predictor of diastolic dysfunction compared with pulse pressure and other PWV markers, such as heart–carotid PWV, heart–femoral PWV, carotid–femoral PWV or femoral–ankle PWV.[27,28] We have shown that increased baPWV was associated with cardiac diastolic function as indicated by *E/A* ratio. Therefore, to our knowledge, this is the first community-based study to report that increased baPWV might be a risk factor or marker for diastolic dysfunction.

A previous study in Japan has shown a significant association between *E/A* ratio and baPWV in 147 patients with hypertension.[9] We have consistently found that baPWV was a significant predictor (cross-sectionally) of LV diastolic dysfunction in a community sample, independent of multiple potential confounders, such as age, mean arterial blood pressure and lipids. Estimation of baPWV using an automatic oscillometric method to identify early diastolic dysfunction among those with normal EF function may have important pathological and clinical implications. Our findings have provided consistent and complementary information and suggested that, early screening and treatment of arterial stiffness was important for preventing diastolic heart failure, especially in older people. However, the cross-sectional nature of the study does not allow us to determine whether increased baPWV preceded the ecocardiographic detected diastolic dysfunction.

We also found that after adjusting for age, increased carotid IMT was associated with increase LVMI and posterior wall thickness. However, such associations could not be observed after adjusting for other potential confounders. We found no association between *E/A* ratios and IMT in our population. Previous Western studies in hypertensive patients and with small sample size have shown that carotid IMT was associated with markers of diastolic function[29–33] such as isovolumic relaxation time and DT. However, data on the relationship between *E/A* ratio and carotid IMT were scarce, with only one Japanese study reported an unadjusted insignificant association.[9]We could not determine the precise mechanism underlying the association between diastolic dysfunction and arterial stiffness or atherosclerosis and future longitudinal studies are needed.

Several limitations of this study should be considered. First, the study sample was homogeneous and the association between arterial stiffness and diastolic dysfunction was analysed using cross-sectional data. Thus, further prospective studies are needed to confirm our findings in other populations and to clarify the temporal association between diastolic dysfunction and arterial stiffness. Second, a high percentage of our subjects (31.8%) were hypertensive, with two thirds of them taking blood pressure lowering medication, which to some extent may differentially modify the indices of arterial stiffness and diastolic dysfunction and influence the true relationship between these markers. However, given that hypertension is a common and widespread global epidemic, such limitation can only overcome by stratified analysis in large community-based studies. We have added mean arterial pressure and medication for hypertension in the stepwise multivariate models and the results remained unchanged, but the sample size was not adequate to perform a stratified analysis. Furthermore, our study included an ethnically homogeneous population thus further studies in different ethnic groups taking into account ethnic difference in the prevalence of hypertension are warranted. Third, as this study was not a blinded, interventional trial, we cannot rule out bias in our subjects. However, as the physicians performing all the assessments were blinded to subjects' identity and other clinical information, diagnosis bias was unlikely. Finally, given that carotid–femoral PWV is a validated marker of arterial stiffening over the central elastic arteries,[21] further studies are necessary to compare the baPWV with carotid–femoral PWV in predicting diastolic dysfunction.

In conclusion, this study has shown that baPWV, but not IMT, correlated with diastolic dysfunction, and might be a risk factor or marker for diastolic dysfunction, independent of other potential vascular risk factors. Early detection and intervention of increased baPWV may be important for prevention of cardiac diastolic dysfunction. Further studies are needed to confirm these findings in other populations.

What is known about topic

- Arterial stiffness as measured by brachial–ankle pulse wave velocity (PWV) is a risk factor for atherosclerosis and diastolic heart failure in patients with hypertension.
- It is less clear whether an increased brachial–ankle PWV or carotid intima-medial thickness relates to the left-ventricular diastolic dysfunction in the general population with a normal ejection fraction.

What this study adds

- This study provided evidence that increasing arterial stiffness was an independent risk factor for diastolic dysfunction in a community population with a normal ejection fraction.
- No association between carotid intima-medial thickness and diastolic dysfunction was observed after controlling for multiple potential risk factors.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The study is funded by the National Natural Science Foundation of China/Research Grants Council (No. 30518001; HKU720/05) Grant. The main cohort study was funded by The University of Hong Kong Foundation for Education and Science, Hong Kong; Guangzhou Public Health Bureau, and Guangzhou Science and Technology Committee, Guangzhou, China; and The University of Birmingham, UK. The Guangzhou Cohort Study-Cardiovascular Disease Subcohort (GBCS-CVD) investigators include Guangzhou No. 12 Hospital: Jie Ming Lin, Bin Liu, Xiao Jun Yue, Chao Qiang Jiang (co-PI); The University of Hong Kong: Tai Hing Lam (co-PI); The Chinese University of Hong Kong: Brian Tomlinson, Ka Sing Wong; The University of Birmingham: Bernard MY Cheung, Shahrad Taheri, Paramjit Gill, Greg YH Lip, Kar Keung Cheng, G Neil Thomas (co-PI).

References

1 Yamashina A, Tomiyama H, Arai T, Hirose K, Koji Y, Hirayama Y *et al.* Brachial-ankle pulse wave velocity as a marker of atherosclerotic vascular damage and cardiovascular risk. *Hypertens Res* 2003; **26**(8): 615–622.
2 van Popele NM, Grobbee DE, Bots ML, Asmar R, Topouchian J, Reneman RS *et al.* Association between arterial stiffness and atherosclerosis: the Rotterdam Study. *Stroke* 2001; **32**(2): 454–460.
3 Tomiyama H, Koji Y, Yambe M, Shiina K, Motobe K, Yamada J *et al.* Brachial–ankle pulse wave velocity is a simple and independent predictor of prognosis in patients with acute coronary syndrome. *Circ J* 2005; **69**(7): 815–822.
4 Yu WC, Chuang SY, Lin YP, Chen CH. Brachial-ankle vs carotid-femoral pulse wave velocity as a determinant of cardiovascular structure and function. *J Hum Hypertens* 2008; **22**(1): 24–31.
5 Ren X, Ristow B, Na B, Ali S, Schiller NB, Whooley MA. Prevalence and prognosis of asymptomatic left ventricular diastolic dysfunction in ambulatory patients with coronary heart disease. *Am J Cardiol* 2007; **99**(12): 1643–1647.
6 Redfield MM, Jacobsen SJ, Burnett Jr JC, Mahoney DW, Bailey KR, Rodeheffer RJ. Burden of systolic and diastolic ventricular dysfunction in the community: appreciating the scope of the heart failure epidemic. *JAMA* 2003; **289**(2): 194–202.
7 Fischer M, Baessler A, Hense HW, Hengstenberg C, Muscholl M, Holmer S *et al.* Prevalence of left ventricular diastolic dysfunction in the community. Results from a Doppler echocardiographic-based survey of a population sample. *Eur Heart J* 2003; **24**(4): 320–328.
8 Abhayaratna WP, Marwick TH, Smith WT, Becker NG. Characteristics of left ventricular diastolic dysfunction

in the community: an echocardiographic survey. *Heart* 2006; **92**(9): 1259–1264.
9 Yambe M, Tomiyama H, Hirayama Y, Gulniza Z, Takata Y, Koji Y *et al.* Arterial stiffening as a possible risk factor for both atherosclerosis and diastolic heart failure. *Hypertens Res* 2004; **27**(9): 625–631.
10 Abhayaratna WP, Srikusalanukul W, Budge MM. Aortic stiffness for the detection of preclinical left ventricular diastolic dysfunction: pulse wave velocity versus pulse pressure. *J Hypertens* 2008; **26**(4): 758–764.
11 Jiang CQ, Thomas GN, Lam TH, Schooling CM, Zhang W, Lao X *et al.* Cohort profile: The Guangzhou Biobank Cohort Study, a Guangzhou-Hong Kong-Birmingham collaboration. *Int J Epidemiol* 2006; **35**(4): 844–852.
12 Jiang CQ, Lam TH, Lin JM, Liu B, Yue XJ, Cheng KK *et al.* An overview of the Guangzhou Biobank Cohort Study-Cardiovascular Disease Subcohort (GBCS-CVD): a platform for multidisciplinary collaboration. *J Hum Hypertens* 2010; **24**(2): 139–150.
13 Deng HB, Macfarlane DJ, Thomas GN, Lao XQ, Jiang CQ, Cheng KK *et al.* Reliability and validity of the IPAQ-Chinese: the Guangzhou Biobank Cohort study. *Med Sci Sports Exerc* 2008; **40**(2): 303–307.
14 Jiang CQ, Lao XQ, Yin P, Thomas GN, Zhang WS, Liu B *et al.* Smoking, smoking cessation and aortic arch calcification in older Chinese: the Guangzhou Biobank Cohort Study. *Atherosclerosis* 2009; **202**(2): 529–534.
15 Thomas GN, Young RP, Tomlinson B, Anderson PJ, Woo KS, Sanderson JE *et al.* A sibling-pair analysis of fasting lipids and anthropometric measurements and their relationship to hypertension. *Clin Exp Hypertens* 1999; **21**(7): 1161–1176.
16 Devereux RB, Reichek N. Echocardiographic determination of left ventricular mass in man. Anatomic validation of the method. *Circulation* 1977; **55**(4): 613–618.
17 Lubien E, DeMaria A, Krishnaswamy P, Clopton P, Koon J, Kazanegra R *et al.* Utility of B-natriuretic peptide in detecting diastolic dysfunction: comparison with Doppler velocity recordings. *Circulation* 2002; **105**(5): 595–601.
18 Yamashina A, Tomiyama H, Takeda K, Tsuda H, Arai T, Hirose K *et al.* Validity, reproducibility, and clinical significance of noninvasive brachial-ankle pulse wave velocity measurement. *Hypertens Res* 2002; **25**(3): 359–364.
19 Eren M, Gorgulu S, Uslu N, Celik S, Dagdeviren B, Tezel T. Relation between aortic stiffness and left ventricular diastolic function in patients with hypertension, diabetes, or both. *Heart* 2004; **90**(1): 37–43.
20 Abhayaratna WP, Barnes ME, O'Rourke MF, Gersh BJ, Seward JB, Miyasaka Y *et al.* Relation of arterial stiffness to left ventricular diastolic function and cardiovascular risk prediction in patients $>$ or $=65$ years of age. *Am J Cardiol* 2006; **98**(10): 1387–1392.
21 Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, Hayoz D *et al.* Expert consensus document on arterial stiffness: methodological issues and clinical applications. *Eur Heart J* 2006; **27**(21): 2588–2605.
22 Weber T, O'Rourke MF, Ammer M, Kvas E, Punzengruber C, Eber B. Arterial stiffness and arterial wave reflections are associated with systolic and diastolic function in patients with normal ejection fraction. *Am J Hypertens* 2008; **21**(11): 1194–1202.
23 Roman MJ, Ganau A, Saba PS, Pini R, Pickering TG, Devereux RB. Impact of arterial stiffening on left ventricular structure. *Hypertension* 2000; **36**(4): 489–494.
24 Chae CU, Pfeffer MA, Glynn RJ, Mitchell GF, Taylor JO, Hennekens CH. Increased pulse pressure and risk of heart failure in the elderly. *JAMA* 1999; **281**(7): 634–639.
25 Zile MR, Gaasch WH, Carroll JD, Feldman MD, Aurigemma GP, Schaer GL *et al.* Heart failure with a normal ejection fraction: is measurement of diastolic function necessary to make the diagnosis of diastolic heart failure? *Circulation* 2001; **104**(7): 779–782.
26 How to Diagnose Diastolic Heart Failure. European Study Group on Diastolic Heart Failure. *Eur Heart J* 1998; **19**(7): 990–1003.
27 Safar ME, Levy BI, Struijker-Boudier H. Current perspectives on arterial stiffness and pulse pressure in hypertension and cardiovascular diseases. *Circulation* 2003; **107**(22): 2864–2869.
28 Wang CP, Hung WC, Yu TH, Hsu HL, Chen YH, Chiu CA *et al.* Brachial-ankle pulse wave velocity as an early indicator of left ventricular diastolic function among hypertensive subjects. *Clin Exp Hypertens* 2009; **31**(1): 31–43.
29 Mizuguchi Y, Tanaka H, Oishi Y, Miyoshi H, Emi S, Ishimoto T *et al.* Predictive value of associations between carotid arterial sclerosis and left ventricular diastolic dysfunction in patients with cardiovascular risk factors. *J Am Soc Echocardiogr* 2007; **20**(7): 806–812.
30 Agoston-Coldea L, Mocan T, Bobar C. Arterial stiffness and left ventricular diastolic function in the patients with hypertension. *Rom J Intern Med* 2008; **46**(4): 313–321.
31 Guntekin U, Gunes Y, Gunes A, Ceylan Y, Gumrukcuoglu HA, Yucel Y *et al.* Noninvasive assessment of atherosclerosis in patients with isolated hypertension. *Echocardiography* 2009; **27**(2): 155–160.
32 Meijs MF, Doevendans PA, Cramer MJ, Vonken EJ, Velthuis BK, van der Graaf Y; *et al.* Relation of common carotid intima-media thickness with left ventricular mass caused by shared risk factors for hypertrophy. *J Am Soc Echocardiogr* 2009; **22**(5): 499–504.
33 Parrinello G, Colomba D, Bologna P, Licata A, Pinto A, Paterna S *et al.* Early carotid atherosclerosis and cardiac diastolic abnormalities in hypertensive subjects. *J Hum Hypertens* 2004; **18**(3): 201–205.