



Egyptian Society of Cardiology  
The Egyptian Heart Journal

www.elsevier.com/locate/ehj  
www.sciencedirect.com



# Familial history of hypertension as a predictor of increased arterial stiffness in normotensive offspring



Ghada Youssef<sup>a,\*</sup>, Ibrahim El Tebi<sup>a</sup>, Dina Osama<sup>a</sup>, Ahmed Shehahta<sup>a</sup>,  
Essam Baligh<sup>a</sup>, Zeinab Ashour<sup>a</sup>, Hany Gamal<sup>b</sup>

<sup>a</sup> Department of Cardiovascular Medicine, Faculty of Medicine, Cairo University, Cairo, Egypt

<sup>b</sup> Department of Physiology, Faculty of Medicine, Cairo University, Cairo, Egypt

Received 14 May 2016; revised 26 July 2016; accepted 30 July 2016

Available online 21 August 2016

## KEYWORDS

Arterial stiffness;  
Vascular distensibility;  
Familial hypertension;  
Pulse wave velocity

**Abstract** *Background:* Increased arterial stiffness can be used as a prognostic marker of arterial hypertension. The relationship between arterial stiffness and arterial hypertension seems to be reciprocal.

*Objective:* Evaluation of changes of the arterial elastic properties in normotensive subjects, with and without parental history of hypertension.

*Subjects and Methods:* One hundred and ten normotensive individuals, aged 20–30 years, were divided into two groups: group-A ( $n = 57$ ) and group-B ( $n = 53$ ) subjects with positive and negative parental history of hypertension, respectively. Systolic, diastolic and pulse pressures were measured using mercury sphygmomanometer. The elastic properties of the ascending aorta and the common carotid arteries were assessed using M-mode echo and B-mode imaging, respectively. Stiffness index of the digital volume pulse (SIDVP) was measured in the right index finger using photoplethysmography.

*Results:* Group A subjects showed higher aortic stiffness index ( $p = 0.002$ ), carotid stiffness index ( $p = 0.001$ ), carotid pulse wave velocity ( $p \leq 0.001$ ) and stiffness index of digital volume pulse ( $p = 0.001$ ). Group A subjects showed lower aortic distensibility ( $p = 0.001$ ), aortic strain ( $p = 0.004$ ), changes in aortic diameter ( $p = 0.022$ ), carotid distension ( $p = 0.026$ ), carotid distensibility coefficient ( $p \leq 0.001$ ) and carotid compliance coefficient ( $p = 0.002$ ).

*Conclusion:* The aortic and carotid stiffness parameters and SIDVP were higher in normotensive offspring of hypertensive parents. This finding could direct the attention towards the increased cardiovascular risk in this group and thus prompt earlier and tighter prevention of cardiovascular risk factors.

© 2016 Egyptian Society of Cardiology. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## 1. Introduction

An abnormal large arterial function plays an important role in the pathogenesis of cardiovascular disease.<sup>1</sup> The aortic elastic

\* Corresponding author.

E-mail address: [ghadayoussef@kasralainy.edu.eg](mailto:ghadayoussef@kasralainy.edu.eg) (G. Youssef).

Peer review under responsibility of Egyptian Society of Cardiology.

<http://dx.doi.org/10.1016/j.ehj.2016.07.003>

1110-2608 © 2016 Egyptian Society of Cardiology. Production and hosting by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

properties are important determinants of blood pressure and left ventricular function.

Diastolic blood pressure (DBP) is determined by peripheral arterial resistance, while Systolic blood pressure (SBP) and Pulse pressure (PP) are influenced more by the stiffness of large arteries, as well as, peripheral pulse wave reflection and the pattern of left ventricular ejection.<sup>2,3</sup>

Increased stiffness of the aorta is an important determinant of future increases in Blood pressure (BP) and progression of hypertension.<sup>4-7</sup> The association between vascular stiffness and blood pressure is particularly interesting because the functional relationship is likely bidirectional.<sup>8</sup> Elevated blood pressure may cause vascular damage and accelerated conduit artery stiffness.<sup>8</sup> Conversely, aortic stiffening increases pressure pulsatility and therefore affects systolic blood pressure: not only the aorta, as it also found that higher carotid artery stiffness was associated with incident hypertension.<sup>9</sup>

Offspring of hypertensive have higher blood pressures, weight, height, and body surface area compared to the offspring of normotensive parents.<sup>10</sup>

In addition, family history of hypertension considered a predictor of hypertension that may be a stronger risk factor for hypertension than other factors.<sup>11,12</sup>

Measuring arterial stiffness helps to identify patients at high risk for hypertension and serve to re-emphasize the importance of preserve arterial function in the primary prevention of hypertension.<sup>13</sup> This study hypothesized that offspring of parents with hypertension would have greater arterial stiffness compared with offspring of parents without hypertension.

## 2. Methodology

### 2.1. Study population

One hundred and ten drug-naïve normotensive individuals, including volunteering doctors and nurses, aged 20–30 years, were recruited by a non-randomized way. They were divided into 2 groups, group A, 57 subjects and group B, 53 subjects with positive and negative parental history of hypertension, respectively. Exclusion criteria were diabetes mellitus, chronic renal failure (serum creatinine > 1.4 mg/L) and hypertension. Subjects were asked to refrain from caffeine, smoking and strenuous exercise for 12 h before the study. After a light breakfast following overnight fasting, the subject is asked to rest in bed in the supine position for 15 min. Each subject was evaluated clinically and his/her height and weight were measured and BMI was calculated.

### 2.2. Blood pressure measurements

Blood pressure was measured in the right arm using mercury sphygmomanometer, taking into consideration the appropriate cuff size. Korotkoff phases I and V were used to define the systolic and diastolic blood pressures, respectively. Measurements were taken 3 times per visit, 2 min apart, and were averaged.

### 2.3. Echocardiographic measurements

Transthoracic echocardiography was performed to confirm absence of organic heart diseases and to evaluate the aortic

elastic properties, based on the standards of the American Society of Echocardiography<sup>14</sup> by an experienced echocardiographer, using a commercially available machine (Esaote MyLab 60) with a 2.5 MHz phased-array transducer.

### 2.4. Calculation of the elastic parameters of the aorta (Fig. 1)

The diameter of the ascending aorta was measured in the parasternal long axis view by 2D-guided M-mode tracing. Measurements were taken 3 cm distal to the aortic valve. The systolic diameter was measured at the maximal anterior excursion of the aortic valve, whereas the diastolic diameter was measured at the peak of the QRS complex on the simultaneously recorded electrocardiogram. Three consecutive measurements were taken and averaged. The aortic stiffness index, aortic distensibility and aortic strain were calculated by the following formula:

$$\text{Aortic } \beta \text{ stiffness index} = \ln(\text{SBP}/\text{DBP})/[(\text{SD} - \text{DD})/\text{DD}]^{15}$$

where  $\ln$ , natural logarithm; SBP and DBP, systolic and diastolic blood pressures, respectively; SD = systolic diameter, and DD = diastolic diameter.

$$\text{Aortic strain (\%)} = (\text{SD} - \text{DD})/\text{DD}^{13-15}$$

$$\text{Aortic distensibility (cm}^2/\text{dyne)}$$

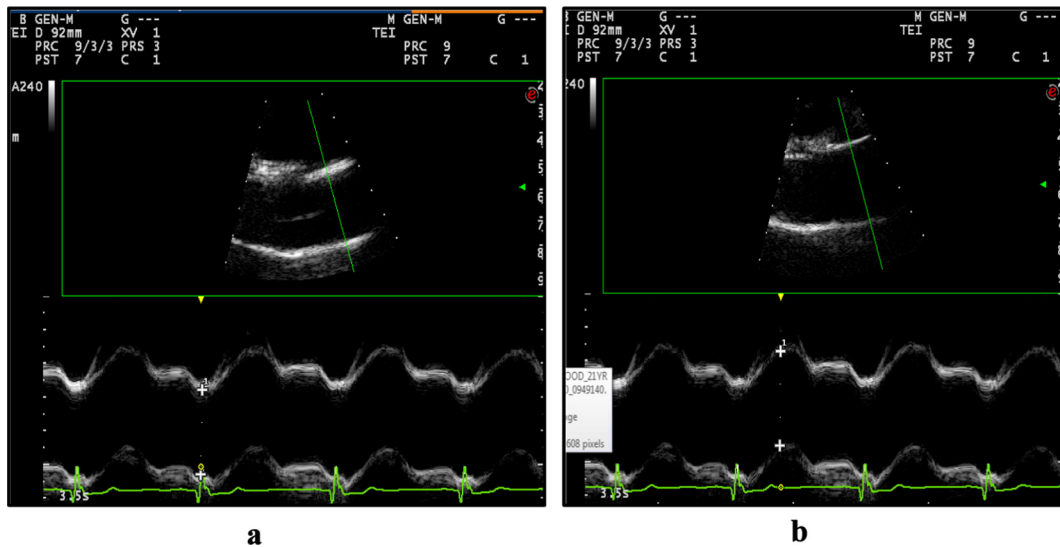
$$= 2 \times (\text{SD} - \text{DD})/[(\text{SBP} - \text{DBP}) \times \text{DD}]^{15}$$

The value obtained from the equation of aortic distensibility should be multiplied to 1333 to convert mmHg to  $\text{cm}^2/\text{dyne}$ .

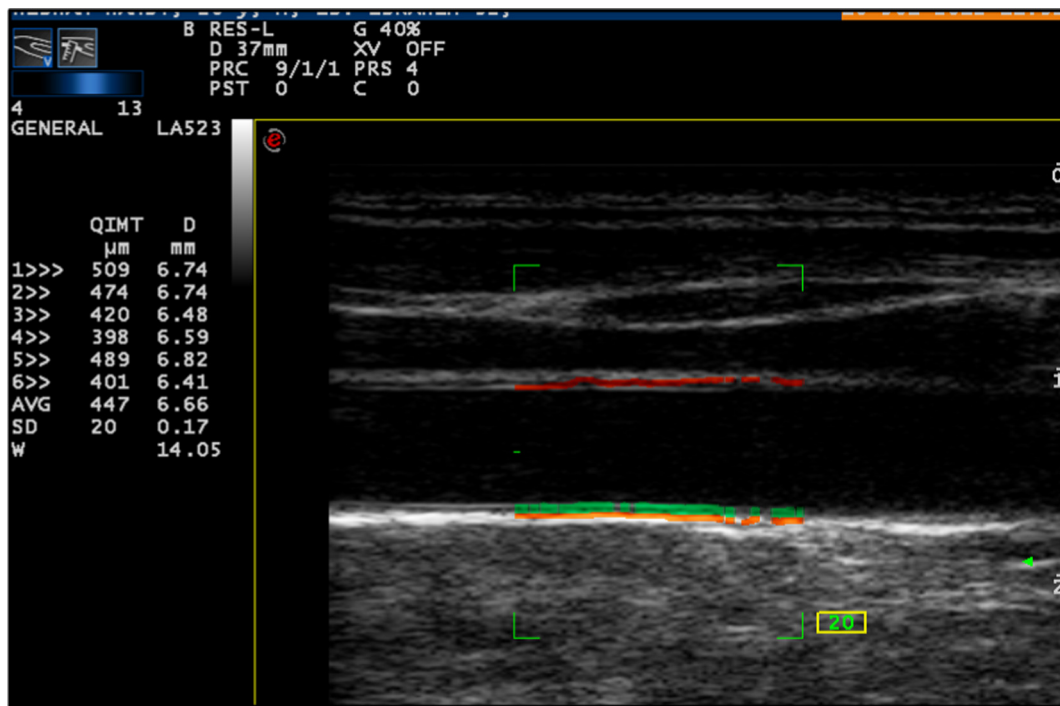
### 2.5. Ultrasound imaging of Common Carotid Artery (CCA) (Figs. 2 and 3)

Measurements of carotid distension were performed by tracking arterial wall movement with adequate spatial and temporal resolution.<sup>16</sup> Longitudinal images of the both CCA, were obtained with linear 10 MHz probe. A rectangular region of interest (ROI) was placed at CCA segment starting approximately 1–2 cm before the carotid bifurcation. Arterial distension was measured in 32 scanning lines positioned within the ROI (sampling rate of 550 Hz on 32 lines). During the acquisition, orange lines indicated the automatic positioning of tracking cursors on the media-adventitia interface, whereas continuous green lines displayed dynamically the amplified vessel wall movement. From the real-time distension curves, displayed in blue at the bottom of the screen, maximum and minimum carotid diameters were measured, carotid distension and minimum diameter in the last six cardiac cycles were presented beat-to-beat on the screen and the mean value and standard deviation were continuously calculated.<sup>16</sup> The local carotid pressure is automatically estimated by converting the distension curve to pressure curve by a linear conversion factor.<sup>16</sup> The peripheral BP was needed for calibration of the distension curves.<sup>16</sup>

The following parameters were automatically calculated: carotid distension, compliance coefficient, distensibility coefficient, pulse wave velocity (PWV), carotid beta-stiffness index and local blood pressure (systolic and diastolic).



**Figure 1** Measurements of diastolic and systolic diameters of the ascending aorta through M-mode imaging on parasternal long axis view, 3 cm distal to the aortic valve. (a) Diastolic assessment of aortic diameter at peak of QRS. (b) Systolic assessment of aortic diameter at maximum excursion of the aortic valve.



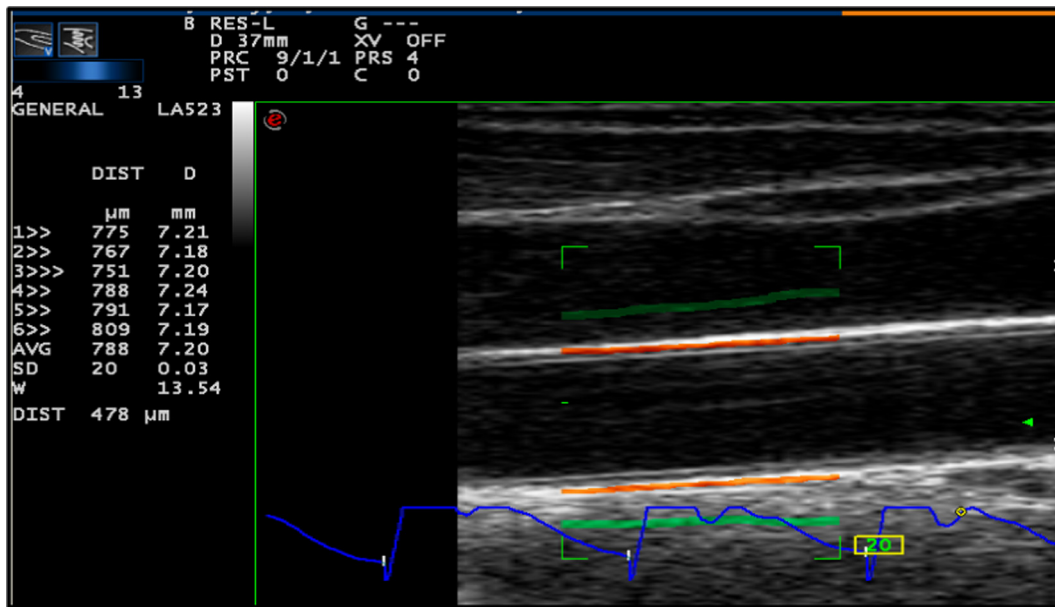
**Figure 2** Quality intima medial thickness (QIMT) measurement. Continuous orange line means perpendicular position of the probe over the carotid artery, continuous green line is needed for proper assessment of IMT, large green box is ROI, small yellow box shows the reading of SD, and when it is green this means that the reading of the IMT is close.

2.6. Assessment of Stiffness index of digital volume pulse (SIDVP)

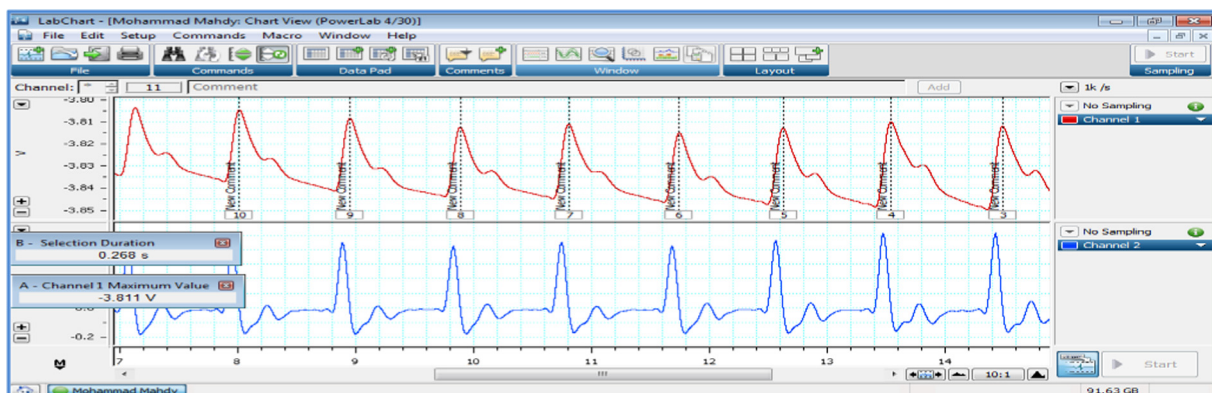
It usually exhibits an early systolic peak and a later peak or point of inflection that occurs short time ( $\Delta TDVP$ ) after the first peak in early diastole.<sup>17</sup>  $\Delta TDVP$  can be used to infer

the transit time taken for pressure to propagate along the aorta and large arteries to the major sites of reflection in the lower body and back to the root of the subclavian artery. This path length is unknown, but can be assumed to be proportional to subject height ( $h$ ).<sup>18</sup>

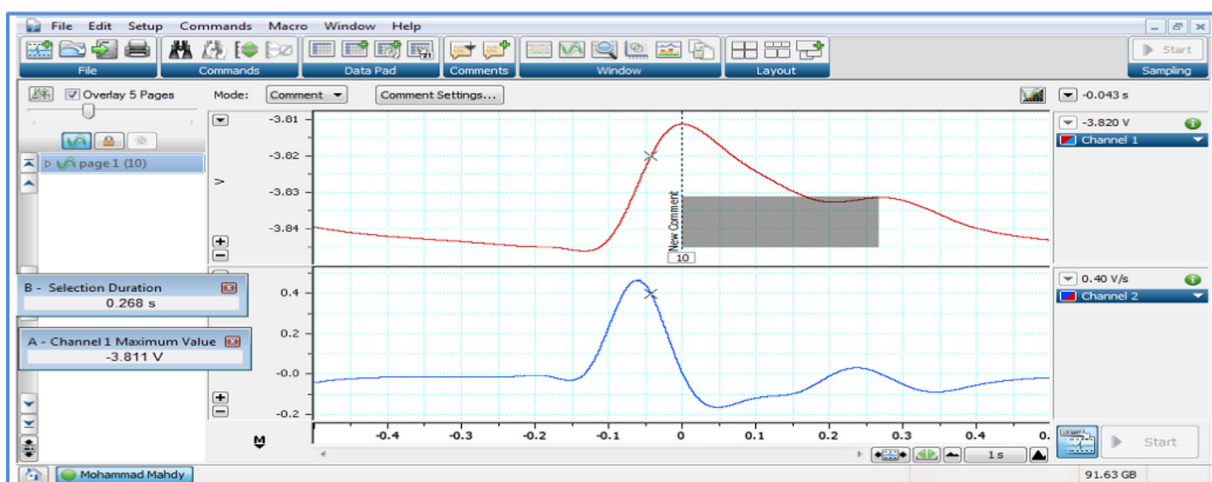
$$SIDVP = h / \Delta TDVP^{17}$$



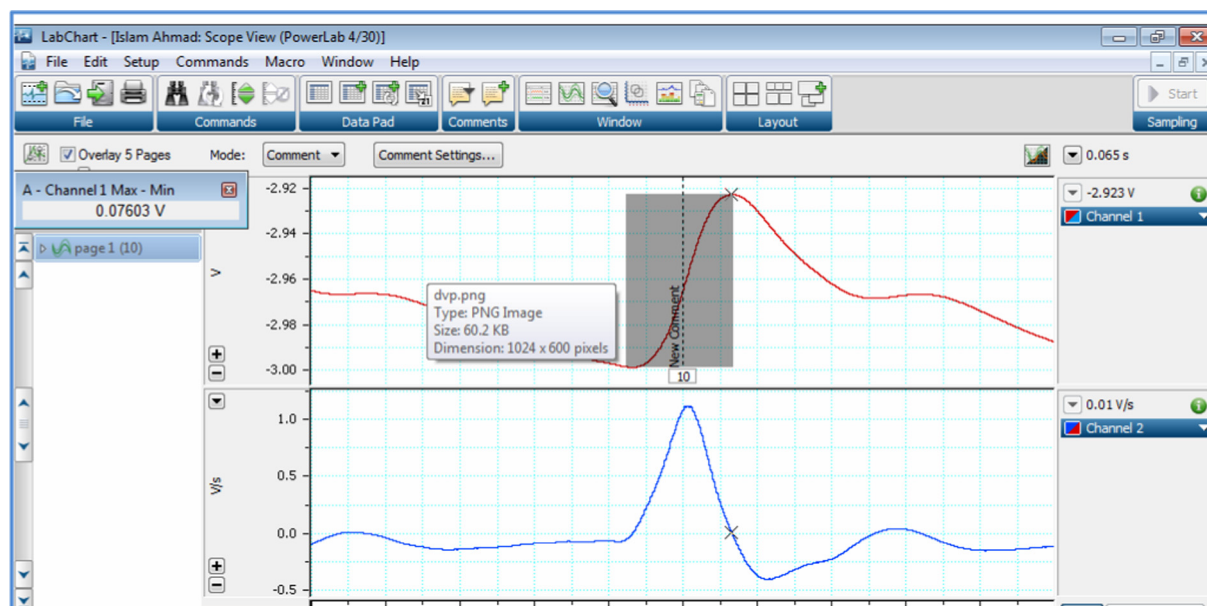
**Figure 3** Diameter wall tracking: Continuous orange lines without interruptions indicate a good detection.



**Figure 4** Digital volume pulse obtained from plethysmography. Upper channel represents pulse waveform, and lower channel represents rate of changes of volume of blood in the digital artery during cardiac phase.



**Figure 5** Upper channel represents averaged waveform, the shaded represents the time difference between reflected wave and forward wave, and lower channel represents the rate of the changes of the blood volume in the digital artery.



**Figure 6** Amplitude of the forward wave.

### 2.7. Acquisition of the DVP and signal processing by Photoplethysmography (Figs. 4–6)

Subjects had to rest in the sitting position for at least 5 min in a temperature controlled environment ( $24 \pm 1^\circ\text{C}$ ) before the measurements were taken. Digital volume pulse was measured using PowerLab 4/35 data acquisition system (ADInstruments, LTD). Digital volume pulse was detected using MLT1020PPG infrared plethysmograph. Signal from the photocell was digitized and analyzed using LabChart software (ADInstruments, LTD). The signal from the plethysmograph was digitized using a 12-bit analogue-to-digital converter with a sampling frequency of 100 Hz. DVP waveforms were recorded over a 20 s period and ensemble-averaged to obtain a single waveform from which  $\Delta TDVP$  was determined.

Volunteers who had an SI variation of  $> 15\%$  within measurements were excluded. All measurements were performed by the same operator. Reflection index was measured as the ratio between the amplitude of the second and first peaks of DVP waveform.

### 2.8. Statistical analysis

Data were collected and analyzed using the Statistical Package for Social Sciences (SPSS) version 18. Data were expressed as

median and range for all parameters to both groups. Independent sample *t*-test was used to compare between both groups. A probability level of  $p$ -value  $\leq 0.05$  was considered as statistically significant in all results obtained. Multiple linear regression analysis was used to assess the association between different variables and arterial stiffness.

## 3. Results

### 3.1. Baseline characteristics of both groups are represented in Table 1

Subjects of both groups were generally young, overweight, having normal systolic and diastolic blood pressure and normal heart rate.

### 3.2. Aortic diameter and aortic elastic parameters (Table 2)

Evaluation of aortic elastic parameters showed that, in comparison with group B subjects, group A subjects had statistically significant higher values regarding aortic systolic diameter, aortic diastolic diameter, change in aortic diameter and aortic stiffness index and lower values regarding aortic distensibility and aortic strain.

**Table 1** The baseline clinical characteristics of both groups.

Variable	Total ( $n = 110$ ) Median (range)	Group A ( $n = 57$ ) Median (range)	Group B ( $n = 53$ ) Median (range)	<i>p</i> Value
Age (years)	26 (20–30)	27 (20–30)	25 (21–30)	0.027
Height (m)	1.75 (1.50–1.91)	1.76 (1.6–1.9)	1.73 (1.5–1.91)	0.117
Weight (kg)	79 (45–123)	80 (60–123)	77 (45–115)	0.038
BMI ( $\text{kg}/\text{m}^2$ )	25.78 (15–38)	27.18 (18.9–38.3)	24.86 (15.03–37.6)	0.033
Systemic systolic pressure (mmHg)	120 (105–140)	130 (110–140)	120 (105–140)	0.003
Systemic diastolic pressure (mmHg)	80 (60–90)	80 (65–90)	80 (60–90)	0.120
Pulse pressure (mmHg)	50 (30–70)	50 (30–70)	45 (30–60)	0.032
Heart rate (BPM)	75 (52–96)	72 (56–96)	76 (52–96)	0.921

**Table 2** Aortic stiffness parameters.

Variable	Total ( <i>n</i> = 110) Median (range)	Group A ( <i>n</i> = 57) Median (range)	Group B ( <i>n</i> = 53) Median (range)	<i>P</i> Value
Aortic systolic diameter (cm)	2.7 (2.2–3.53)	2.81 (2.3–3.53)	2.63 (2.2–3.51)	0.007
Aortic diastolic diameter (cm)	2.49 (1.8–3.35)	2.64 (2.12–3.35)	2.38 (1.8–3.32)	≤0.001
Change in aortic diameter (cm)	0.21 (0.07–0.58)	0.19 (0.09–0.54)	0.24 (0.07–0.58)	0.022
Aortic SI	5.75 (1.55–15.93)	6.36 (1.85–15.93)	4.47 (1.55–15.32)	0.002
Aortic strain (%)	8.39 (3.15–21.56)	7.017 (3.15–19.78)	10.34 (3.16–21.56)	0.004
Aortic distensibility (cm <sup>2</sup> dyne <sup>-1</sup> )	4.6 (1.8–18.1)	4.1 (1.8–13.1)	6.1 (1.9–18.1)	0.001

**Table 3** Carotid stiffness parameters in the study population.

Variable	Total ( <i>n</i> = 110) Median (range)	Group A ( <i>n</i> = 57) Median (range)	Group B ( <i>n</i> = 53) Median (range)	<i>P</i> Value
Carotid distension (μm)	600.5 (242–997)	564 (242–997)	608 (314–939)	0.026
Carotid stiffness index	4.37 (1.77–11.25)	5.1 (2.09–11.25)	4.19 (1.77–9.90)	0.001
Carotid PWV (m/s)	4.98 (3.39–8.57)	5.32 (3.39–8.57)	4.74 (3.52–6.91)	≤0.001
Local carotid systolic pressure (mmHg)	112 (93–139)	118 (94–139)	108 (93–133)	0.01
Local carotid diastolic pressure (mmHg)	80 (60–90)	80 (65–90)	80 (60–90)	0.061
QIMT (μm)	619 (342–701)	523 (364–701)	511 (342–687)	0.365
Distensibility coefficient (1/kpa)	0.04 (0.01–0.08)	0.03 (0.01–0.08)	0.04 (0.02–0.08)	≤0.001
Compliance coefficient (m <sup>2</sup> /kpa)	1.47 (0.50–3.22)	1.24 (0.50–2.88)	1.54 (0.73–3.22)	0.002

**Table 4** DVP parameters.

Variable	Total ( <i>n</i> = 110) Median (range)	Group A ( <i>n</i> = 57) Median (range)	Group B ( <i>n</i> = 53) Median (range)	<i>P</i> Value
First peak amplitude (V)	0.077 (0.0008–1.95)	0.0792 (0.0008–0.23)	0.071 (0.0008–1.95)	0.844
Second peak amplitude (V)	0.030 (0.0002–0.39)	0.026 (0.0003–0.11)	0.035 (0.0002–0.39)	0.816
Time difference between two peaks (M/S)	0.204 (0.100–0.29)	0.179 (0.100–0.298)	0.226 (0.100–0.273)	0.003
Stiffness index	8.37 (5.87–17.8)	9.64 (5.87–17.8)	7.73 (5.93–17.64)	0.001
Reflection index	0.384 (0.16–0.68)	0.379 (0.16–0.65)	0.39 (0.18–0.68)	0.271

**Table 5** Multiple linear regression analysis between parental history of hypertension and arterial stiffness.

Parameter	Family history of hypertension Beta coefficient	<i>P</i> Value
Stiffness index DVP	0.273	0.005
Aortic stiffness index	0.218	0.028
Aortic distensibility	−0.255	0.008
Aortic strain	−0.232	0.016
Carotid distension	−0.185	0.053
Carotid stiffness index	0.336	0.001
Carotid PWV	0.351	≤0.001
Distensibility coefficient	−0.309	0.001
Compliance coefficient	−0.256	0.009

### 3.3. Carotid elastic parameters (Table 3)

Evaluation of carotid elastic parameters showed that, in comparison with group B subjects, group A subjects had statistically significant lower values regarding carotid distension, distensibility coefficient and compliance coefficient and they

had higher values regarding carotid stiffness index and carotid PWV.

### 3.4. Digital volume pulse parameters (Table 4)

Group A subjects showed statistically significant higher SIDVP and time difference between systolic and diastolic peaks. This signifies that the pulse wave traveled faster in group A subjects, who had higher stiffness index.

It was found that the presence of a parental history of hypertension is a powerful predictor of increased arterial stiffness in their offspring, as described in Table 5.

## 4. Discussion

Increased arterial stiffness has been shown to be associated not only with age but also with several other vascular risk factors, especially hypertension and diabetes mellitus.<sup>19</sup> Consequently, it is regarded as a summary measure for vascular damage caused by other risk factors. Furthermore, arterial stiffness seems to be a vascular risk factor itself, as it was shown to be independently related to the risk of stroke, myocardial

infarction, and cardiovascular death.<sup>20,21</sup> It has been reported that hypertensive adults have a twofold increase in arterial stiffness values compared to normotensives<sup>22</sup>. Arterial stiffening is considered as a consequence of arterial hypertension and other cardiovascular risk factors. However, recent evidence suggests that arterial stiffening may exist without the presence of arterial hypertension, which allows the hypothesis that it may be both a cause and effect of arterial hypertension.<sup>23</sup> Recent studies suggest that offspring of hypertensive parents have higher blood pressure values<sup>24</sup> and increased left ventricular mass.<sup>25</sup> While many studies were conducted concerning arterial stiffness assessment in adults, only a few studies refer to younger subjects<sup>26,27</sup>

Measuring systemic blood pressure using the conventional sphygmomanometer techniques, we found that group (A) subjects, with parental history of hypertension, had significantly higher systolic and pulse pressures than group B subjects, with normotensive parents. It was also found that pulse, and not systolic blood pressure, might be an indicator of increased arterial stiffness. These results were similar to the results found by Yasmin et al.<sup>28</sup> who observed that offspring of hypertensive compared with normotensive parents had higher systolic/diastolic BP (123/75 vs. 118/71 mmHg). They also reported that offspring of hypertensive parents had higher peripheral pulse pressure (49 vs. 47 mmHg;  $P \leq 0.01$ ).

Aortic elastic properties were determined by M-mode echocardiography, and it was found that group A subjects had higher aortic stiffness index, less distensibility and less aortic strain, meaning that they had higher aortic stiffness compared to group B subjects. Similar results were found by Harun et al.<sup>29</sup> who studied a total of 140 healthy, non-obese subjects in the age group of 18–22 years and showed that the aortic stiffness index was higher, but aortic distensibility and strain were lower in offspring of hypertensive parents, compared to offspring of normotensive parents. Kyvelo et al.<sup>30</sup> studied a similar group of subjects and also found that the offspring with at least one parent with arterial hypertension had higher arterial stiffness indices compared to offspring with normotensive parents, independently of age and blood pressure levels or other confounders.

It was found that the carotid stiffness index and carotid PWV were higher and carotid distension, carotid distensibility coefficient as well as carotid compliance coefficient were lower in subjects with hypertensive parents, which implied that the carotid stiffness was higher in group A subjects.

These results were similar to those of Meaney et al.<sup>31</sup> who studied 100 non-obese subjects, aged 10–20 years and were descendants of hypertensive or normotensive parents. They studied the characteristics of the ascending aorta using M-mode echocardiography and the common carotid artery bi-dimensional images. Carotid, but not aortic stiffness, and maximum velocity flow in the aorta were significantly higher in the offspring of the hypertensive parents; the comparisons were, however, not adjusted for BP which was already higher in this group.

It was found that, the stiffness index of DVP (SIDVP) and the time difference between the first and second peaks were higher in offspring of hypertensive parents. Millasseau et al.<sup>18</sup> used DVP to determine age-related increases in large arterial stiffness by digital pulse contour analysis and concluded that SIDVP, derived from the DVP is correlated with pulse wave

velocity between carotid and femoral artery (PWVcf), which is the gold standard method in measuring PWV.

In multivariate analyses<sup>32</sup> it was found that large-artery properties are altered in offspring of hypertensive parents compared with offspring of normotensive parents, but their findings from that cross-sectional study suggest that the alterations in arterial function in offspring of hypertensive parents are determined mainly by an increased blood pressure and age-related hemodynamic changes.

Limitations of our study included absence of pulse wave velocity measurements by tonometry which is the gold standard technique of measuring the arterial stiffness. The study subjects were predominantly males which preclude us to do valid statistical analysis to evaluate gender effect on arterial stiffness in this age group.

To summarize, in non-hypertensive subjects with no overt cardiovascular disease or symptoms at baseline, aortic elastic properties can predict the increase in systolic BP, diastolic BP, and pulse pressure beyond the prediction provided by risk factors including initial level of BP.

So we recommend early screening of arterial stiffness in any individual with parental history of hypertension, as increased arterial stiffness is an antecedent factor of hypertension.

## 5. Conclusion

This study concluded that arterial stiffness parameters were higher in normotensive subjects of hypertensive parents. This finding could direct the attention toward the increased cardiovascular risk in this group and thus prompt earlier and tighter prevention of cardiovascular risk factors.

## 6. Conflict of interest

There is no conflict of interests regarding this study.

## References

1. O'Rourke MF, Nichols WW. Aortic diameter, aortic stiffness and wave reflection increase with age and isolated systolic hypertension. *Hypertension* 2005;**45**:652–8.
2. Krieger J, Grucker D, Sforza E, et al. Left ventricular ejection fraction in obstructive sleep apnea: Effects of long-term treatment with nasal continuous positive airway pressure. *Chest* 1991;**100**:917–21.
3. Franklin S, Gustin W, Wong N, et al. Hemodynamic patterns of age-related changes in blood pressure: the Framingham Heart Study. *Circulation* 1997;**96**:308.
4. Woodman J, Gerald F. Watts Measurement and application of arterial stiffness in clinical research: focus on new methodologies and diabetes mellitus Signature. *Med Sci Monit* 2003;**9**(5):81–9.
5. Takase H, Dohi Y, Toriyama T, et al. Brachial ankle pulse wave velocity predicts increase in blood pressure and onset of hypertension. *Am J Hypertens* 2011;**24**(6):667–73.
6. Dernellis J, Panaretou M. Aortic stiffness is an independent predictor of progression to hypertension in non-hypertensive subjects. *Hypertension* 2005;**45**(3):426–31.
7. Najjar S, Scuteri A, Shetty V, et al. Pulse wave velocity is an independent predictor of the longitudinal increase in systolic blood pressure and of incident hypertension in the Baltimore Longitudinal Study of Aging. *J Am Coll Cardiol* 2008;**51**(14):1377–83.
8. Aatola H, Hutri-Kahonen N, Juonala M, et al. Lifetime risk factors and arterial pulse wave velocity in adulthood; the

- Cardiovascular Risk in Young Finns Study. *Hypertension* 2010;**55**(3):806–11.
9. Bernhard M, Rong J, Larson M, et al. Aortic stiffness, blood pressure progression and incident hypertension. *JAMA* 2012;**308**(9):875–81.
  10. Blond C, Webber L, Foster T, et al. Parental history and cardiovascular disease risk factor variables in children. *Prev Med* 1981;**10**:25–37.
  11. Tozawa M, Oshiro S, Ieski C, et al. Multiple risk factor clustering of hypertension in screened cohort. *J Hypertension* 2000;**18**:1379–85.
  12. Tozawa M, Oshiro S, Ieski C, et al. Multiple risk factor clustering of hypertension in screened cohort. *J Hypertension* 2000;**24**:93–8.
  13. Dernellis J, Panaretou M. Aortic Stiffness is an independent predictor of progression to hypertension in non-hypertensive subjects. *Hypertension* 2005;**45**:426–31.
  14. Lang R, Bierig M, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group; European Association of Echocardiography. University of Chicago Hospitals, Chicago, IL, USA. *J Am Soc Echocardiogr* 2005;**18**(12):1440–63.
  15. Fahey M, Ko H, Srivastava S, et al. A comparison of echocardiographic techniques in determination of arterial elasticity in the pediatric population. *Echocardiography* 2009;**26**(5):567–73.
  16. Palombo Carloa, Kozakova Michaelab, et al. Radiofrequency-based carotid wall tracking: a comparison between two different systems. *J Hypertens* 2012;**30**(8):1614–9.
  17. Brillante D, O'Sullivan A, Howes L. Arterial stiffness indices in healthy volunteers using non-invasive digital photoplethysmography. *Blood Press* 2008;**17**(2):116–23.
  18. Millasseau S, Kelly R, Ritter J, et al. Determination of age-related increases in large artery stiffness by digital pulse contour analysis. *Clin Sci* 2002;**103**:371–7.
  19. Benetos A, Waeber B, Izzo J, et al. Influence of age, risk factors, and cardiovascular and renal disease on arterial stiffness: clinical applications. *Am J Hypertens* 2002;**15**:1101–8.
  20. Laurent S, Boutouyrie P, Asmar R, et al. Aortic stiffness is an independent predictor of all-cause and cardiovascular mortality in hypertensive patients. *Hypertension* 2001;**37**:1236–41.
  21. Boutouyrie P, Tropeano AI, Asmar R, et al. Aortic stiffness is an independent predictor of primary coronary events in hypertensive patients: a longitudinal study. *Hypertension* 2002;**39**:10–5.
  22. Alva F, Samaniego V, Gonzales V, et al. Structural and dynamic changes in the elastic arteries due to arterial hypertension and hypercholesterolemia. *Clin Cardiol* 1993;**16**:614–8.
  23. Yasmin, Brown MJ. Similarities and differences between augmentation index and pulse wave velocity in the assessment of arterial stiffness. *Q J Med* 1999;**92**:595–600.
  24. Blonde C, Webber L, Foster T, et al. Parental history and cardiovascular risk factor variables in children. *Prev Med* 1981;**10**:25–37.
  25. Celentano A, Galderisi M, Garofalo M, et al. Blood pressure and cardiac morphology in young children of hypertensive subjects. *J Hypertens* 1988;**6**:107–9.
  26. Kucerova J, Filipovsky J, Staessen J. Arterial characteristics in normotensive offspring of parents with or without a history of hypertension. *Am J Hypertens* 2006;**19**:264–9.
  27. Kyvelou S-M, Vyssoulis G, Karpanou E, et al. Arterial stiffness in offspring of hypertensive parents: a pilot study. *Int J Cardiol* 2008;**129**:438–40.
  28. Yasmin, Falzone R, Brown M. Determinants of arterial stiffness in offspring of families with essential hypertension. *Am J Hypertens* 2004;**17**:292–8.
  29. Evrengul Harun, Tanriverdi Halil, Ismail D, et al. Aortic stiffness and flow mediated dilatation in normotensive offspring of parents with hypertension. *Cardiol Young* 2012;**22**:451–6.
  30. Kyvelou SM, Vyssoulis GP, Karpanou EA, et al. Arterial hypertension parental burden affects arterial stiffness and wave reflection to the aorta in young off springs. *Int. J. Cardiol.* 2009;**144**:156–60.
  31. Meaney E, Samaniego V, Alva F, et al. Increased arterial stiffness in children with parental history of hypertension. *Pediatr Cardiol* 1999;**20**:203–5.
  32. Kucerova J, Filipovsky J, Staessen J, et al. Arterial characteristics in normotensive offspring of parents with or without a history of hypertension. *Am J Hypertens* 2006;**19**(3):264–9.