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Research Article

PULSE WAVE VELOCITY AND ITS USEFULNESS IN THE ESTIMATION OF HYPERTENSION

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ABSTRACT

Objective: "Arterial vessel wall stiffness" is an important determinant of cardiovascular disease (CVD). Prolonged hypertension causes deterioration in the blood vessel elasticity. Hypertension can be prevented by early diagnosis. Pulse wave velocity (PWV) is the direct method for assessing the arterial stiffness. Though numerous studies have been performed, the definite limit is not declared to evaluate CVD based on the threshold of PWV for South Indian population.

Methods: In this study, we included a total of 246 healthy controls and 14 hypertensive patients. Mechanical variables of blood flow are measured using PC-based periScope Device (Genesis Medical Systems, India). The following variables are measured from the normal controls and hypertensive patients: (i) Heart rate (bpm), (ii) systolic blood pressure (SBP) (mmHg), (iii) diastolic blood pressure (DBP) (mmHg), (iv) brachial PWV (baPWV) (cm/s), (v) carotid-femoral PWV (C-F PWV) (cm/s), (vi) pulse pressure (mm Hg), (vii) arterial stiffness index (ASI) (mmHg), (viii) ankle-brachial index (ABI), (ix) aortic SBP and DBP (mmHg), and (x) aortic augmentation pressure (mmHg).

Results: The study shows the deterioration in the vessel elasticity with advancing age in both men and women. In the normal men population studied (n=135), an increase in SBP from a young age to older age was 3.7%, likewise in women (n=111), it was 12%. A standard cutoff value of 1738 cm/s for baPWV and 1215 cm/s for C-F PWV was calculated from the combined group of known hypertensive patients and age- and sex-matched normal controls.

Conclusion: Thus, the PWV and the variables derived from it can be used for evaluating the status of blood vessels noninvasively.

Keywords: Vascular stiffness, Pulse wave velocity, Gender, Carotid-femoral, Hypertensive.

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INTRODUCTION

Hypertension is related to the risk of development of stroke and coronary disease. Many pharmacoeconomic studies reveal an enormous expenditure involved in the treatment of high blood pressure [1]. Hence, an efficient diagnostic method for hypertension is the need of the hour. Reduced compliance or the vasculature distensibility leads to arterial stiffness which is the leading cause of high blood pressure. Pulse wave velocity (PWV) is the measure of arterial stiffness. Arterial wall stiffness is mainly dependent on the blood pressure and the blood cholesterol level. Before the onset of atherosclerosis, there is a significant stiffening of the arteries due to the deposition of small fatty lipids. PWV is the direct method for assessing the arterial stiffness, whereas the augmentation index is the indirect way to evaluate the same. The augmentation index is the measurement of the effect of stiffness on the aorta. Thus, the measurement of the arterial stiffness index (ASI) and augmentation index gives an estimation of the central blood pressure, which is a measure of the patient's arterial vascular system [2]. The abnormalities in the vascular system are an indicator of peripheral vascular disease.

The most common method to measure PWV is oscillometric technique, where the velocity of the blood is calculated from the pressure pulse waveform. It is generated by the ventricular ejection, which travels through the arteries. The graph of this amplitude of the oscillation, measured using the blood pressure cuff in the limbs, is called oscillometric envelope. The distance between the heart and the respective limb divided by the pulse transit time gives the PWV of the own limb. The oscillometric technique provides more relevant and reproducible results [3]. Naidu *et al*. concluded in their pilot study that the oscillometric periScope device is a simple, non-invasive device with excellent reproducibility [4]. Yashmaina *et al*. evaluated the patients with arterial stiffness who were at a high risk of cardiovascular disease (CVD). PWV measured from the patients was highly correlated statistically with the standard arterial stiffness parameter, confirming that PWV can be an independent predictor for CVD [5]. The standard variables for the evaluation of end-organ damage are intima-media thickness (IMT) and low estimated glomerular filtration rate according to Matsumoto *et al*. who postulated that the measured baPWV in hypertensive patients showed the statistically significant difference when compared to the healthy controls [5,6]. Shanker *et al*. studied the cumulative effects of various biomarkers of atherosclerosis by calculating the PWV, ASI, and AIx in asymptomatic individuals using oscillometric device [3]. Numerous community-based studies have been conducted to evaluate the CVD risk factors using the statistical Tukey's *post hoc* analysis [6].

Although studies employ the mechanical blood flow variables to examine the hemodynamic properties of the blood vessels, there is no defined threshold for the CVD risk, especially for the South Indian population. Hence, the aim of this study was to collect normative data for mechanical blood flow variables measured using periScope in South Indian men and women and to determine their cutoff value for healthy controls and hypertensive patients. Statistical significance of these variables verified in known hypertensive patients was compared with age- and sex-matched healthy controls.

MATERIALS AND METHODS

In a private hospital, we organized a free screening camp for hypertensive patients during September 2013. The total number of registered patients of both sexes was 300, and their age ranged from 18 to 70 years. The institutional Ethical Committee had approved the study (17/IEC/2010). An informed consent form was obtained from all patients. A detailed questionnaire prepared for this study was administered to each patient, and the details were noted. Of the total patients enrolled, 40 were known cases of fever, neurological disorders, diabetes mellitus, thyroid abnormalities, and nephropathy, and thus they were excluded from this study. Of the 260 patients, 246 were normal, and the remaining 14 were hypertensive cases. The data were analyzed separately for healthy controls and hypertensive subjects as Study-I and Study-II, respectively. The study groups are as follows:

A. Study-I: It comprised 246 participants, who were normal, i.e., they had no hypertension; their age ranged from 18 to 66 years (mean±standard deviation (SD) age= 34.2±8.7 years). The participants are classified into two groups as follows:
   - Group-I: Normal men (n=135, mean±SD age =36±11.33 years)
   - Group-II: Normal women (n=111, mean±SD age =32.4±7.5 years).
B. Study-II: It comprised a total of 28 patients, with and without hypertension. The patients are classified into two groups as follows:
   - Group-I: Known hypertensive patients (n=14, male/women=9/5, mean±SD age=39.3±10.5 years), average years since hypertension=2±0.6 years
   - Group-II: Age- and sex-matched normal controls (n=14, men/women=9/5, mean±SD age =39.7±12.2 years).

Methods

PC-based periScope device (Genesis Medical Systems, India) was used to measure the various mechanical variables of blood flow. The participants were asked to lie in the supine position. After 2-minute resting period, the cuffs are placed on the forearm and legs for measurement of blood pressure. Based on the oscillometric technique, the pressure pulse waveform of the forearm and legs was captured. Simultaneous acquisition of 3-lead electrocardiogram (ECG) was also made. From the ECG and oscillometric envelope, the following variables were measured directly: (i) Heart rate (bpm), (ii) systolic blood pressure (SBP) (mmHg), (iii) diastolic blood pressure (DBP) (mmHg), and (v) pulse pressure (mmHg). In addition, the following variables were derived from the measured pulse pressure waveform: (i) aortic SBP (mmHg), (ii) aortic pulse pressure (mmHg), (iii) aortic DBP (mmHg), (iv) aortic augmentation pressure (mmHg), (v) carotid-femoral PWV (C-F PWV) (cm/s), (vi) BaPWV (bilateral) (cm/s), (vii) brachial ASI (mm Hg), (viii) ankle ASI (mm Hg), and (ix) ankle-brachial index (ABI).

Statistics

In study-I, both Groups I (healthy men) and II (healthy women) were divided into three tertiles separately based on the patient's age (years) and their corresponding measured SBP (mmHg) using Tukey's *post hoc* analysis. The Tukey's *post hoc* analysis determines which tertile in the sample differs significantly based on patient's age and SBP. Independent t-test was carried out to investigate the significance of variables measured between the known hypertensive patients (Group-I) and the normal age- and sex-matched controls (Group-II). All the data were analyzed using IBM SPSS statistical software package version 10.0.

RESULTS

Patient's limb side-specific variation

In study-I, the calculated mean±SD values of derived mechanical blood flow variables measured on the left and right sides of both upper and lower limbs of both healthy men as well as women studied are listed in Tables 1 and 2, respectively. It was found that, in both healthy men and women, there was no significant statistical difference between the variables mentioned above measured in the left and right sides of the limbs.

Patient's age-specific variation

Healthy men (Group-I): In healthy men (n=135, mean±SD age=36.0±11.3 years), the linear regression analysis showed a statistically significant correlation between age (years) and the mechanical variables of blood flow as shown in Figs. 1-3.

Healthy women (Group-II): In normal women (n=111, mean±SD age=32.4±7.5 years), the linear regression analysis showed a statistically significant correlation between age (years) and variables as illustrated in Figs. 4-6.

Patient's sex-specific variation

Table 3 provides a comparison of both direct and derived mechanical blood flow variables using periScope between healthy men (Group-I) and women (Group-II). In healthy men (Group-I), the percentage increment was greatest for pulse pressure with 15.7% $\left[\left(57.29-48.31/57.29\right)\times 100\right]$ Also, in Group-I, in the mean values of all the derived mechanical blood flow variables concerned, the percentage increment was greatest for aortic augmentation pressure with 74% $\left[\left(6.42-1.61/6.42\right)\times 100\right]$.

Patient's age and SBP variation

Both Groups I and II (healthy men and women) are subdivided into three tertiles based on the patient's age (years) and their corresponding measured SBP (mmHg) using Tukey's *post hoc* analysis as shown in Tables 4 and 5.

Healthy men

The healthy young men (tertile-I) were compared with tertiles II and III as shown in Table 6.

i. With tertile-II

   In middle-aged men (tertile-II), in the mean values of the variables concerned, the calculated percentage decrement was greatest for pulse pressure with 12% $\left[\left(61.21-53.55/61.21\right)\times 100\right]$, and the estimated percentage increment was highest for C-F PWV with 20% $\left[\left(881.44-730.06/730.06\right)\times 100\right]$.

ii. With tertile-III

Table 1: Comparison of patient's limb side-specific variation in normal men

Study-I: Group-I: Normal men (n=135, mean±SD age=36.0±11.3 years)		
Mechanical variables of blood flow measured using periScope	**Left side**	**Right side**
Arm		
baPWV (cm/s)	1307.68±286.16	1322.03±282.68
Brachial ASI mmHg)	25.52±6.59	25.8±8.07
Leg		
Ankle ASI (mm Hg)	33.04±10.41	34.97±9.04
Leg-to-arm pressure ratio		
ABI	1.1±0.13	1.15±0.09

Table 2: Comparison of patient's limb side-specific variation in normal women

Study-I: Group II: Normal women (n=111, mean±SD age=32.4±7.5 years)		
Mechanical variables of blood flow measured using periScope	**Left side**	**Right side**
Arm		
baPWV (cm/s)	1044.63±278.87	1096.2±206.04
Brachial ASI (mmHg)	21.04±7.2	22.67±6.52
Leg		
Ankle ASI (mmHg)	29.27±10.01	31.75±9.05
Leg-to-arm pressure ratio		
ABI	1.08±0.09	1.1±0.14

Table 3: Comparison between the patient's sex-specific variations with the mean±SD values of the mechanical variables of blood flow measured using periScope

Variables	Group I: Normal men (n=135, mean±SD age=36.0±11.3 years)	Group II: Normal women (n=111, mean±SD age=32.4±7.5 years)	Statistical significance (p-value)
Demographic variables			
Body weight (kg)	70.58±12.59	64.3±12.96	<0.01
Body height (m)	1.69±0.08	1.57±0.06	<0.01
BMI (kg/m^2)	24.83±4.06	26.08±5.09	<0.05
Mechanical variables of blood flow (periScope)			
a. Directly measured			
Heart rate (bpm)	76.86±12.24	77.56±9.3	NS
SBP (mmHg)	133.56±16.22	118.48±13.1	<0.01
DBP (mmHg)	76.42±10.44	70.25±9.34	<0.01
Pulse pressure (mmHg)	57.29±10.7	48.31±8.53	<0.01
b. Indirectly derived variables			
Derived pressure			
Aortic SBP (mmHg)	113.05±15.99	96.73±13.32	<0.01
Aortic pulse pressure (mmHg)	36.5±8.58	26.98±7.69	<0.01
Aortic DBP (mmHg)	76.06±9.75	69.29±8.47	<0.01
Aortic augmentation pressure (mmHg)	6.42±4.9	1.61±4.84	<0.01
Neck			
C-F PWV (cm/s)	857.52±216.18	708.89±419.42	<0.01
Arm			
baPWV (cm/s)	1314.85±268.48	1070.42±190.73	<0.01
Brachial ASI (mmHg)	25.8±8.07	22.67±6.52	<0.01
Leg			
Ankle ASI (mmHg)	34.34±8.49	30.55±8.42	<0.05
Leg-to-hand pressure ratio			
ABI	1.12±0.1	1.09±0.1	<0.05

*NS-Not significant, SD: Standard deviation, SBP: Systolic blood pressure, ABI: Ankle-brachial index, ASI: Arterial stiffness index, baPWV: Carotid-femoral pulse wave velocity, DBP: Diastolic blood pressure

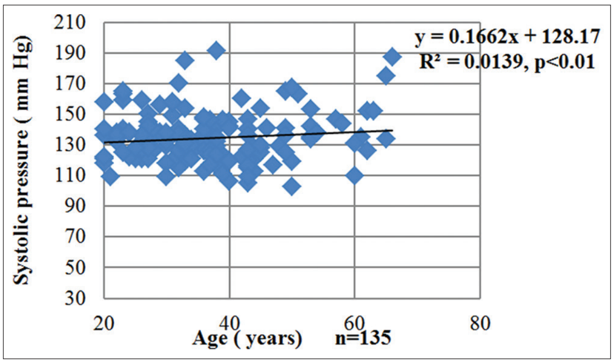

Fig. 1: Linear regression analysis of age versus systolic blood pressure (mmHg) in normal men

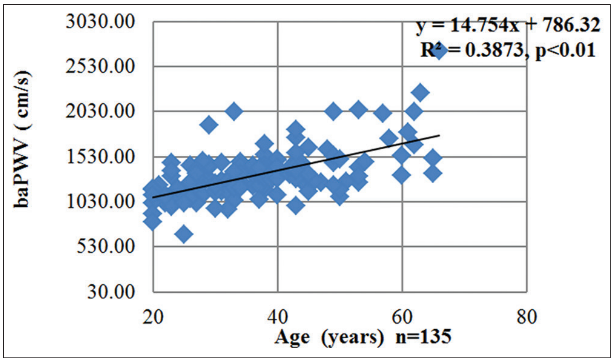

Fig. 2: Linear regression analysis of age versus brachial pulse wave velocity (cm/s) in normal men

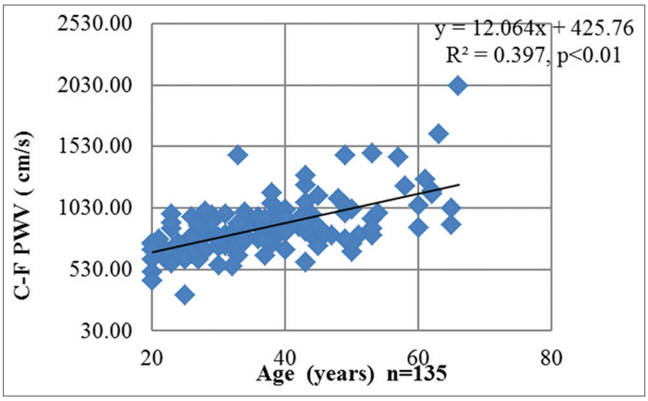

Fig. 3: Linear regression analysis of age versus carotid-femoral pulse wave velocity (cm/s) in normal men

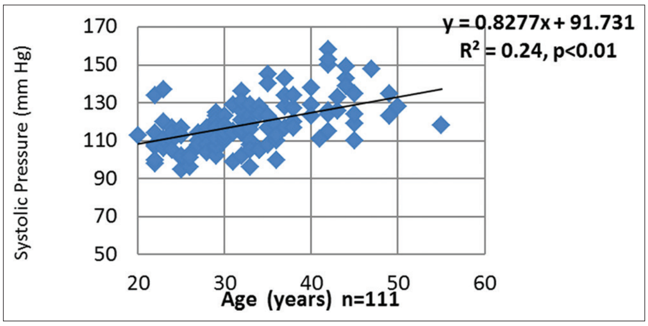

Fig. 4: Linear regression analysis of age versus systolic blood pressure (mmHg) in normal women

In older aged men (tertile-III), the mean value of pulse pressure was significantly ($p<0.01$) less than those in young men (tertile-I), whereas the mean values of the variables concerned, the calculated percentage increment was greatest for C-F PWV with 40% $\left[\left(\frac{1032.45-730.06}{730.06}\right)\times 100\right]$.

iii. Between Tertiles II and III

In middle-aged men (tertile-II), in the mean values of the variables concerned, the calculated percentage decrement was greatest for baPWV with 17% $\left[\left(\frac{1032.45-881.44}{881.44}\right)\times 100\right]$.

Healthy women

The healthy young women (tertile-I) were compared with tertiles II and III as shown in Table 7.

i. With tertile-I

In middle-aged women (tertile-II), in the mean values of the variables concerned, the calculated percentage increment was greatest for baPWV with 12% $\left[\left(\frac{1068.17-948.48}{948.48}\right)\times 100\right]$.

ii. With tertile-III

In older-age women (tertile-III), in the mean values of the variables concerned, the percentage increment was greatest for baPWV with 25% $\left[\left(\frac{1192.15-948.48}{948.48}\right)\times 100\right]$.

iii. Between tertiles II and III

In middle-aged women (tertile-II), in the mean values of the variables concerned, the calculated percentage decrement was greatest for aortic augmentation pressure with 76% $\left[\left(\frac{3.3-0.76}{0.76}\right)\times 100\right]$.

Comparison of hypertensive patients with normal controls

Mechanical blood flow variables measured using periScope device in known hypertensive patients and normal age- and sex-matched controls are shown in Table 8. It was found that, in known hypertensive patients (Group-I), the mean value of aortic augmentation pressure was highest with 63% increment in Group-I when compared to Group-II.

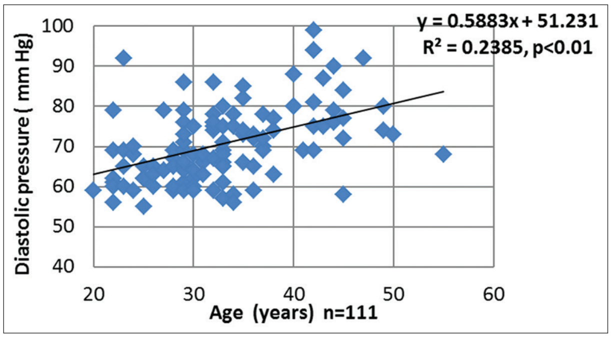

Fig. 5: Linear regression analysis of age versus diastolic blood pressure (mmHg) in normal women

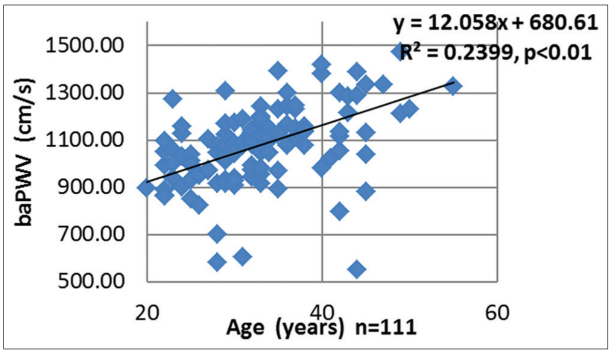

Fig. 6: Linear regression analysis of age versus brachial pulse wave velocity (mmHg) in normal women

Hypertensive threshold values

Using the baPWV and C-F PWV data (Table 8), a threshold for hypertension was arbitrarily defined as the 90th percentile for hypertensive patients. For both men and women, the determined threshold values of baPWV (cm/s) and C-F PWV (cm/s) for hypertension were 1738 cm/s (1332.33-[270.39×1.5]) and 1215 cm/s (876.9-[225.33×1.5]), respectively. In one Indian study (Yashmaina *et al*., 2007) [5], the published threshold values of baPWV (cm/s) and C-F PWV (cm/s) for hypertension were >1400 cm/s and >900 cm/s, respectively, whereas, in one Korean study (Kim *et al*., 2005), the same were > 1600 cm/s and > 1300 cm/s, respectively [7].

Normal controls

Using the calculated threshold when the estimated hypertension threshold value of baPWV (cm/s) was used in normal men and women (study-I/Groups-I and II), it was found that 8% of men $\left[\left(\frac{11}{135}\right)\times 100\right]$ and 0.9% of women $\left[\left(\frac{1}{111}\right)\times 100\right]$ were above this threshold. When the estimated hypertension threshold value of C-FPWV (cm/s) was used in normal men and women, it was found that 5% of men $\left[\left(\frac{7}{135}\right)\times 100\right]$ and 1.8% of women $\left[\left(\frac{2}{111}\right)\times 100\right]$ were above this threshold. When the estimated hypertension threshold value of both baPWV (cm/s) and C-FPWV (cm/s) was used in normal men, 5% of them were found to have increased risk for high blood pressure. When the calculated hypertension threshold value of both baPWV (cm/s) and C-FPWV (cm/s) was used in normal women, none of them was found to have increased risk for hypertension.

Using the threshold value suggested by Yashmaina *et al*., for baPWV (cm/s) in healthy men and women (Study-I/Groups-I and II), it was found that 31% of men $\left[\left(\frac{42}{135}\right)\times 100\right]$ and 2.7% of women $\left[\left(\frac{37}{111}\right)\times 100\right]$ were above this threshold. When the hypertension threshold value as specified by Yashmaina *et al.* was used for C-F PWV (cm/s) in normal men and women, it was found that 37% of men $\left[\left(\frac{507}{135}\right)\times 100\right]$ and 7.2% of women $\left[\left(\frac{8}{111}\right)\times 100\right]$ were above this threshold. When the hypertension threshold value as specified by Yashmaina *et al.* was used for both baPWV (cm/s) and C-FPWV (cm/s) in normal men and women, it was found that 17% of men $\left[\left(\frac{23}{135}\right)\times 100\right]$

Table 4: Normal men Group-I subdivision

Tertile	Age range (years)	Group-I: Normal men
Tertile-I (young age)	18-30	n=49, mean±SD age=24.4±3.8 years
Tertile-II (middle age)	31-43	n=61, mean±SD age=37±3.8 years
Tertile-III (older age)	Greater than 43	n=25, mean±SD age=52.8±7.5 years

SD: Standard deviation

Table 5: Normal women Group-II subdivision

Tertile	Age range (years)	Group-I: Normal men
Tertile-I (young age)	18-29	n=33, mean±SD age=23.9±2.9 years
Tertile-II (middle age)	29-35	n=42, mean±SD age=31.6±2.0 years
Tertile-III (older age)	<35	n=36 mean±SD age=41.8±4.6 years

SD: Standard deviation

Table 6: Comparison of mechanical blood flow variables in normal men based on age versus SBP using Tukey's *post hoc* analysis

Study-I: Group I: Normal men (n=135, mean±SD age=36.0±11.3 years)						
Variables	**Tertile-I: Young age 18-30 years (n=49, mean±SD=24.4±3.8 years)**	**Tertile-II: Middle age 31-43 years (n=61, mean±SD=37.0±3.8 years)**	**Tertile-III: Older age>43 years (n=25, mean±SD=52.8±7.5 years)**	**Statistical significance (p-value)**		
				Tertile I versus II	**Tertile I versus III**	**Tertile II versus III**
Demographic variables						
Body weight (kg)	69.23±13.04	70.22±12.95	73.83±10.6	NS	NS	NS
Body height (m)	1.7±0.08	1.67±0.07	1.7±0.07	<0.05	<0.05	NS
BMI (kg/m^2)	23.93±4.39	25.18±4.02	25.67±3.3	<0.05	NS	NS
Mechanical variables of blood flow (periScope)						
a. Directly measured						
Heart rate (bpm)	76.44±11.08	78.55±12.7	73.83±12.9	<0.05	NS	NS
SBP (mm Hg)	133.62±13.44	131.31±16.04	138.52±20.22	<0.05	<0.05	<0.05
DBP (mmHg)	72.71±8.71	77.83±10.47	79.9±11.54	<0.01	<0.01	NS
Pulse pressure (mmHg)	61.21±9.33	53.55±9.76	58.62±12.39	<0.001	<0.001	<0.05
b. Indirectly derived						
Derived pressure						
Aortic SBP (mm Hg)	110.31±12.38	111.75±14.69	120.86±21.71	NS	NS	<0.05
Aortic pulse pressure (mmHg)	37.04±6.79	34.4±7.23	40.24±12.34	<0.05	<0.05	<0.05
Aortic DBP (mmHg)	72.83±8.24	76.82±9.57	80.17±10.98	<0.05	<0.05	NS
Aortic augmentation pressure (mmHg)	5.12±3.76	6±3.57	9.69±7.39	NS	NS	<0.05
Neck						
C-F PWV (cm/s)	730.06±142.6	881.44±146.59	1032.45±304.4	<0.001	<0.001	<0.05
Arm						
baPWV (cm/s)	1165.62±195.9	1337.78±175.9	1531.07±376.34	<0.001	<0.001	<0.05
Brachial ASI (mm Hg)	26.88±5.55	21.69±3.05	23.71±9.27	<0.001	NS	<0.05
Leg						
Ankle ASI (mm Hg)	32.34±7.94	32.6±6.41	40.13±10.78	NS	<0.001	<0.05
Leg to hand pressure ratio						
ABI	1.08±0.08	1.11±0.08	1.09±0.08	<0.01	<0.01	NS

*NS-Not significant, SD: Standard deviation, SBP: Systolic blood pressure, ABI: Ankle-brachial index, ASI: Arterial stiffness index, C-F PWV: Carotid-femoral pulse wave velocity, DBP: Diastolic blood pressure

and 0.9% of women $\left[\left(1/111\right)\times 100\right]$ were above this threshold and, therefore, found to have increased risk for hypertension.

Using the threshold as suggested by Kim *et al*. for baPWV in healthy men and women (Study-I/Group-I&II), it was found that 10% of men $\left[\left(14/135\right)\times 100\right]$ and 0.9% of women $\left[\left(71/111\right)\times 100\right]$ were above this threshold. When the estimated hypertension threshold value as specified by Kim *et al*. was used for C-F PWV (cm/s) in healthy men and women, it was found that 3.7% of men $\left[\left(5/135\right)\times 100\right]$ and 1.8% of women (2%) were above this threshold. When the hypertension threshold value as specified by Kim *et al*. of both baPWV (cm/s) and C-FPWV(cm/s) was used in healthy men, 2.2% $\left[\left(3/135\right)\times 100\right]$ of them were found to have increased risk for high blood pressure. When the calculated hypertension threshold value of both baPWV (cm/s) and C-F PWV (cm/s) was used in healthy women, none of them were found to have increased risk for hypertension. Figs. 7 and 8 show the distribution of the total population in the different threshold for brachial and C-F PWV.

DISCUSSIONS

Nicole *et al*. in their cohort study for a population of 4024 participants measured the arterial stiffness variables from the right side only to save time as the right and left side arterial stiffness variables were correlated [8]. In our study, it was found that, in healthy men and women, the measured baPWV, brachial ASI, ankle ASI, and ABI showed no significant statistical difference between the left and right sides.

Shanker *et al*. studied the relation of carotid IMT with mechanical variables of blood flow. In the study population of 710 participants, both carotid IMT and mechanical blood flow variables were measured. It was reported that arterial stiffness variables were higher in men than in women. Also as reported by Lama *et al*., male gender was one of the factors for uncontrolled BP [9]. In our study, it was found that the mean values of SBP and pulse pressure were higher in normal men by 12% and 18%, respectively, when compared to those values in healthy women. Hence, all the derived variables from the pressure pulse waveform such as PWV, ASI, ABI, and aortic pressure showed a statistically significant higher value in men than women. Of these variables, the percentage increment was greatest for aortic augmentation pressure with 74% $\left[\left(6.42-1.61/6.42\right)\times 100\right]$.

According to the Guidelines for Assessment of CVD in asymptomatic adults released by the American College of Cardiology (2009), advancing age is one of the non-modifiable risk factors. The deterioration in the vessel elasticity with advancing age is reported in numerous studies. Rogers *et al*. studied the patient's age-associated changes in PWV, measured by the MRI-based method. It was concluded that, with increasing age, the arterial stiffness increases [10]. In a health survey conducted by Koivistoinen *et al*., in 1754 participants, there was an increase in vessel stiffness variables with advancing age [11]. A similar trend was observed in our study. In the men population, though the SBP decreases from tertiles I to II (1.5%), it increases in the tertiles II-

Table 7: Comparison of mechanical blood flow variables in normal women based on age versus SBP using Tukey's *post hoc* analysis

Study I: Group II: Normal women (n=111, mean±SD age=32.4±7.5 years)						
Variables	**Tertile‑I: Young age, 18–29 years, (n=33, mean±SD age=23.97±2.86 years)**	**Tertile‑II: Middle age 29‑35 years, (n=42, mean±SD age=31.6±2.04 years)**	**Tertile‑III: Older age>35 years (n=36, mean±SD age=41.81±4.6 years)**	**Statistical significance (p value)**		
				Tertile I versus II	**Tertile I versus III**	**Tertile II versus III**
Demographic details						
Body weight (kg)	58.69±12.69	64.73±12.31	69.14±12.32	<0.05	NS	<0.05
Body height (m)	1.59±0.07	1.56±0.06	1.56±0.06	NS	NS	NS
BMI (kg/m^2)	23.16±3.85	26.52±5.2	28.27±4.77	<0.05	NS	<0.05
Mechanical variables of blood flow (periScope)						
a. Directly measured						
Heart rate (bpm)	75.71±10.36	76.31±8.3	81.11±8.81	NS	<0.05	<0.05
SBP (mm Hg)	111.4±10.44	116.43±10.11	128.28±13.64	<0.05	<0.001	<0.001
DBP (mm Hg)	65.11±7.2	69.18±7.78	76.75±9.64	<0.05	<0.001	<0.001
Pulse pressure (mm Hg)	46.69±7.9	47.14±8.73	51.56±8.16	<0.05	<0.05	<0.05
b. Indirectly derived						
Derived pressure						
Aortic SBP (mm Hg)	89.86±11.87	94.37±9.71	104.73±9.69	NS	NS	NS
Aortic pulse pressure (mm Hg)	24.6±8.91	25.75±6.45	30.53±5.72	NS	NS	NS
Aortic DBP (mm Hg)	64.89±6.39	68.08±7.11	73.77±6.5	NS	NS	NS
Aortic augmentation pressure (mm Hg)	0.6±7.29	0.76±2.63	3.3±2.88	NS	<0.001	<0.001
Arm						
baPWV (cm/s)	948.48±155.78	1068.17±125.83	1192.15±222.37	<0.001	<0.05	<0.001
Brachial ASI (mm Hg)	19.46±6.98	21.79±8.8	23.06±5.93	NS	<0.05	NS
Neck						
C‑F PWV (cm/s)	988.48±155.78	1038.17±125.83	1180.15±222.37	<0.001	<0.05	<0.001
Leg						
Ankle ASI (mm Hg)	28.48±7.36	28.3±8.39	35.62±7.34	NS	<0.001	<0.001
Leg to hand pressure ratio						
ABI	1.07±0.09	1.07±0.1	1.1±0.09	NS	<0.001	<0.05

* NS‑Not significant, SD: Standard deviation, SBP: Systolic blood pressure, ABI: Ankle‑brachial index, ASI: Arterial stiffness index, baPWV: Brachial pulse wave velocity, DBP: Diastolic blood pressure

Table 8: Statistical comparison of known hypertensive patients and normal controls

Variable	**Group I: Known hypertensive (n=14, male/women=9/5, mean±SD age=39.3±10.5 years)**			**Group II: Age‑ and sex‑matched controls (n=14, men/women=9/5, mean±SD age=39.7±12.2 years)**			**Statistical significance (p‑value)**
	Minimum	**Maximum**	**Mean±SD**	**Minimum**	**Maximum**	**Mean±SD**	
Demographic details							
Body weight (Kg)	52	93	74.07±12.72	50	93	67.43±11.82	NS
Body height (cm)	152	176	166.29±8.1	151	174	161.07±7.88	NS
Mechanical variables of blood flow (periScope)							
a. Directly measured							
Heart rate (bpm)	59	89	77.7±9.09	60	92	72.14±8.62	NS
SBP (mmHg)	128	158	140.29±10.05	103	138	118.64±9.54	<0.01
DBP (mmHg)	61	114	81.71±13.94	59	75	68.14±5.81	<0.05
Pulse pressure (mmHg)	43	70	58.5714±9.24	37	68	50.78±8.94	<0.05
b. Indirectly derived							
Derived pressure							
Aortic SBP (mmHg)	82	137	117.69±14.93	85	112	99.85±9.11	<0.01
Aortic pulse pressure (mmHg)	21	51	37.42±7.88	16	41	27.92±7.11	<0.01
Aortic DBP (mmHg)	62	108	81.35±11.3	60	74	68.35±4.79	<0.05
Aortic Aug pressure (mmHg)	–2	18	7±4.54	–3	15	2.57±4.39	<0.05
Arm							
baPWV (cm/s)	945.35	2010.4	1332.33±270.39	857.7	1406.55	1069.91±157.5	<0.05
Brachial ASI (mmHg)	15.4	38.1	26.05±6.26	14.9	30.4	23.73±5.07	NS
Neck							
C‑F PWV (cm/s)	554.4	1441.9	876.9±225.33	481.4	938.7	658.22±131.24	<0.05
Leg							
Ankle ASI (mmHg)	22.6	43.8	35.43±6.32	21.5	41.4	32.50±4.85	NS
Leg to hand ratio							
ABI	0.61	1.23	1.09±0.16	0.96	1.24	1.13±0.07	NS

*NS‑Not significant, SD: Standard deviation, SBP: Systolic blood pressure, ABI: Ankle‑brachial index, ASI: Arterial stiffness index, C‑F PWV: Carotid‑femoral pulse wave velocity, DBP: Diastolic blood pressure

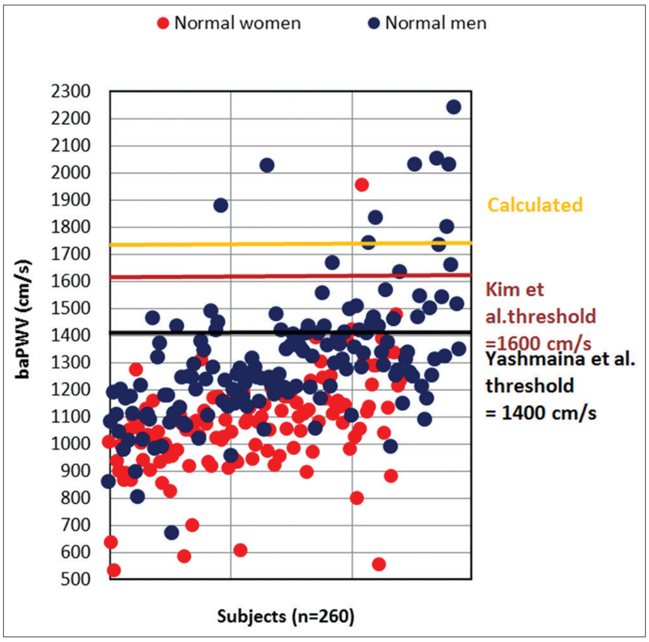

Fig. 7: Distribution of brachial pulse wave velocity according to the various threshold values in known hypertensive patients and normal controls (Study-I and II, Group-I and II)

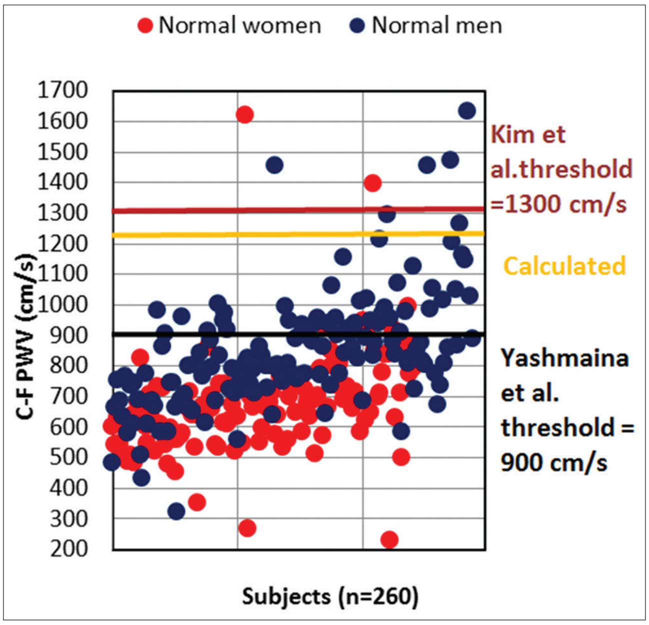

Fig. 8: Distribution of carotid-femoral pulse wave velocity according to the various threshold values in known hypertensive patients and normal controls

III (3.7%). For women, there is a steady rise in the SBP, 6% from tertiles I-II and 12% from tertiles II to III. Hence, all the derived variables from the pulse pressure, PWV, ASI, and aortic pressure increased with advancing age.

To establish the reference value for European population, Boutouyrie *et al.* studied the distribution of PWV in 16,867 patients, out of which 11,092 were healthy controls. The mean PWV differed in men and women with p<0.001. The PWV and pulse pressure gradually increased with age [12,13]. In our study, the mechanical variables of blood slowly rose from tertiles I to III for women. For men, though tertile II showed a lesser pulse pressure than tertile I, the mean PWV and ASI increased in tertile III. The traditional method of evaluating the hypertension is based on the SBP. With recent advancements, numerous variables such as PWV and ASI also contribute to the early detection of hypertension and thereby predict future CVD events. In the study by Kola *et al*., the PWV and ASI were higher significantly in hypertensive and chronic hypertensive subjects. The vascular stiffness variables remained higher in hypertensive patients compared to normal controls even after the drug therapy (amlodipine monotherapy along with polytherapy) [14]. In our study, the mean SBP was 13% more in known hypertensive patients compared to healthy controls. All the derived mechanical variables of blood flow were higher for hypertensive patients, where left baPWV showed 26% increase in the hypertensive patients when compared to the healthy controls. In conclusion, the mechanical variables of the blood flow can be a reliable tool in the evaluation of CVD. They evaluated the status of the arteries noninvasively. It is gender dependent on men having a higher value that strengthens the fact that male gender is one of the risk factors for CVD.

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