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Relationship between anthropometric indices and arterial stiffness: Insights from an epidemiologic study

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Abstract

Background: Obesity and arteriosclerosis are both independently associated with cardiovascular disease risk. Obesity also may increase arterial stiffness.

Aims: This study aimed to investigate the association between anthropometric indices and non-invasive arterial stiffness parameters, using data from a large population-based cohort of seemingly healthy women and men.

Methods: A total of 5023 eligible participants were included in the study. The pulse wave velocity (PWV), central blood pressures, and bio-impedance measures were obtained at the time of enrollment. Multiple regression analysis was performed to assess the relationship between anthropometric indices with arterial stiffness parameters.

Results: The mean age of participants was 45.3 ± 8.8 years, 2368 (47.1%) were males and 2655 (52.8%) were females. The prevalence of participant with underweight, normal weight, overweight, and obesity were 0.73%, 33.2%, 48.7%, and 17.2% respectively. Systolic and diastolic blood pressure, fatty liver, and hypertension were significantly higher in overweight/obesity participants. The overweight/obesity participants had significantly higher PWV than the normal-weight group (471.5 ± 42.6/496.7 ± 47.5 cm/s vs. 448.1 ± 41.4 cm/s, $p < 0.001$).

Conclusion: The prevalence of diabetes, hypertension, fatty liver disease, chronic lung disease, and also kidney stones were significantly higher in overweight and individuals with obesity. Body mass index, body fat mass, waist–hip ratio abdominal circumference, neck circumference, visceral fat area, total body water, 50-kHz whole body phase angle are positively correlated with PWV. Augmentation index had no significant correlation with body mass index, arm, hip, and abdominal circumferences.

KEYWORDS
anthropometric indices, arterial stiffness, chronic disease, cohort

1 | INTRODUCTION

Ischemic heart disease and stroke are the most common causes of death around the world.[1] Obesity and arteriosclerosis are both independently associated with cardiovascular disease (CVD) risk in both genders, and obesity may increase arterial stiffness independent of hypertension and age.[2] Ageing of arteries is related to increased stiffening, and enhanced reflection of the pulse waveform is considered as an important cardiovascular risk factor.[3] Measures of pulse wave velocity (PWV) and augmentation index (AIx) are the two main approaches for assessing arterial stiffness.[3]

The advantage of anthropometry is that the available methods are simple, inexpensive, and non-invasive.[4] The main elements of anthropometry are body mass index (BMI), height, weight, skin fold thickness, and body circumferences (waist, hip, and limbs).[5] These measurements are important because they can represent diagnostic standards for obesity, which considerably reflect the risk for conditions such as diabetes mellitus, hypertension, ischemic heart diseases, myocardial infarction, chronic lung disease, and kidney stones.[6–11] Previous studies have shown that an increased BMI is associated with enhanced PWV, therefore, increased arterial stiffness. However, there are few studies presenting any pathophysiological relationships between the quantity of body fat and the various indices of arterial stiffness, such as systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP).[12]

As studies in various countries and ethnicities claimed that anthropometric measures have different prognostic value for arterial stiffness, the predictive power of anthropometric indices should be recognized for different ethnicities.[2,3] Therefore, using data from a large population-based cohort of seemingly healthy Persian women and men, this study aimed to investigate the association between novel and traditional anthropometric indices to evaluate PWV parameters.

2 | MATERIALS AND METHODS

The population of this study was derived from the Prospective Epidemiological Research Studies in Iran (PERSIAN), which is a nationwide cohort study launched in the year 2014 in an attempt to encourage research in the fields of medicine, epidemiology, health, and nutrition. PERSIAN Organizational Cohort Study in Mashhad (POCM) includes extensive information on baseline status and regular checkup of 12,000 employees (aged 30–70 years) in different organizations in Mashhad, northeast of Iran. All participants included in the PERSIAN cohort study were evaluated over a period of 4 years (August 2017–May 2021). Detailed national protocol has been published in an article by Poustchi et al.[13] The informed consent was obtained from participants prior to the baseline assessment. The study protocol was in accordance with the principles laid down in the Helsinki declaration and has been approved by the national and regional ethics committee (IR.MUMS.REC.1395.526).

The body composition test was performed using the InBody 770 body analyzer (InBody Corporation). The machine sends a weak alternative current (50–1000 kHz) and determines the mass of different body tissues (i.e., body water, muscle, fat, protein, and mineral) by measuring the reflected current. Also calculates the basal metabolic rate (BMR, lowest sustainable energetic expenditure of maintaining the body) and body phase angle (BFA, novel marker of cellular function which represents the quality of soft tissue with higher values reflecting better cell function). The individuals were asked to abstain from caffeine consumption for at least 24 h and any drink or food for at least 4 h prior to the test. The participants were required to stand motionless keeping the standard position (standing barefoot on the footplates while holding hand electrodes with straight arms and no touches in the armpits area). The height was measured in standing position with elevated shoulders and in inspiration using a wall tape and was recorded in centimeters. Weight was measured in parallel with the analysis of body composition using a digital bio-impedance analyzer (In Body 770) with light clothes and to the nearest 0.1 kg. For the assessment of hip circumference, around the widest part of the buttocks was measured. Other measurements such as abdominal, neck, arm, and chest circumferences were measured to the nearest one decimal point in centimeters using National Institutes of Health protocols,[14] while the participant was shoeless and had light underclothes. All the measurements were recorded in centimeters. The person who conducted measurements is trained and expert and has been approved by the scientific team of the Cohort Center. Moreover, the body surface area (BSA) was calculated as the squared root of weight $(\mathrm{kg}) \times$ height (cm) divided by 3600.[14] The pregnant women and the patients who had implanted pacemaker were excluded from the body analysis. In order to obtain technical error of measurement, three exerted anthropometrics measured some of the participations in two different days always in the morning and all measurements obtained were acceptable.

The PWV and central blood pressure (CBP) analyses were performed using the SphygmoCor XCEL System (AtCor Medical Incorporation).[15] The participants were asked to remain in fasting state for at least 6 h and have no tobacco, alcohol, or caffeine use for at least 12 h before performing the test. The test was performed non-invasively in two steps after 10–15 min rest in supine position. First, the CBP measures were derived from the central pressure waveform at the brachial artery which was recorded by the cuff pulsations during three consecutive inflation–deflation cycles. Second, in PWV, an ultrasound tonometer on carotid pulse and a cuff placed around the thigh were used to measure the velocity of arterial pulse from descending aorta to femoral artery. Moreover, the machine was also able to measure the AIx which is the percentage of central pulse pressure due to late systolic peak.

Baseline characteristics of the study population were dichotomized based on BMI. Continuous variables were expressed as mean $\pm$ standard deviation and discrete variables were expressed as percentages. Differences between groups were tested using the independent-samples *t*-test for continuous variables and Chi-square test (or Fisher's Exact) for categorical variables. Pearson's correlation test was also used to assess the relationship between

anthropometric indices and PWV variables. Moreover, a multivariate linear regression model was used to determine the relationship between PWV and the initial set of significant variables which showed $p < 0.05$ in univariate analysis. All statistical analyses were performed using SPSS statistical software version 25, and $p < 0.05$ was considered statistically significant.

3 | RESULTS

The sample of this study consisted of 5023 participants including 2368 (47.1%) males and 2655 (52.8%) females, which were divided into four groups according to the BMI (underweight <18.5, normal = 18.5–24.9, overweight = 25–29.9, obese >30). The baseline characteristics such as demographic, bio-impedance, arterial stiffness, and clinical history are shown in Table 1. The mean age was 45.3 ± 8.8 years. Thirty-seven participants (0.73%) were underweight, 1670 participants (33.2%) were normal weight, 2450 participants (48.7%) were overweight and 866 participants (17.2%) were obese. SBP and DBP, fatty liver, and hypertension were significantly higher in overweight/obesity participants than in the under/normal weight group. The overweight/obesity participants had significantly higher PWV than the normal-weight group (471.5 ± 42.6/496.7 ± 47.5 cm/s vs. 448.1 ± 41.4 cm/s, $p < 0.001$).

Pearson correlation showed BMI was significantly and positively correlated with PWV ($r = 0.18$, $p < 0.001$), SBP ($r = 0.28$, $p < 0.001$), and DBP ($r = 0.23$, $p < 0.001$). But there was no significant correlation between BMI and AIx ($r = -0.02$, $p > 0.05$). 50-kHz whole body phase angle was positively associated with PWV, AIx, SBP, DBP, and MAP ($p < 0.001$). There was a significant

TABLE 1 Demographic, bio-impedance, arterial stiffness, and clinical history of the study population

Variable	Underweight (*N* = 37)	Normal (*N* = 1670)	Overweight (*N* = 2450)	Obese (*N* = 866)	Total (*N* = 5023)	*p*-value
Age (years)	44.5 ± 9.1	43.9 ± 8.7	45.6 ± 8.7	47.2 ± 9.0	45.3 ± 8.8	<0.001
Gender (male)	18 (48.6%)	755 (45.2%)	1217 (49.7%)	378 (43.6%)	2368 (47.1%)	0.004
Bio-impedance measures						
Weight (kg)	48.6 ± 6.4	63.4 ± 8.1	75.0 ± 9.3	87.4 ± 12.2	73.1 ± 12.8	<0.001
Height (cm)	166.4 ± 10.5	165.9 ± 9.2	165.6 ± 9.4	163.5 ± 10.0	165.3 ± 9.5	<0.001
Arterial stiffness measures						
Central SBP (mmHg)	107.2 ± 7.2	114 ± 12.4	119.5 ± 13.1	125.5 ± 14.0	118.6 ± 13.6	<0.001
Central DBP (mmHg)	68.1 ± 6.4	70.7 ± 8.1	73.7 ± 8.7	76.8 ± 9.9	73.2 ± 9.0	<0.001
Central MAP (mmHg)	81.2 ± 6.6	453.1 ± 1875.0	477.2 ± 1923.3	413.4 ± 1753.2	455.3 ± 1871.7	<0.001
PWV (m/s)	421.4 ± 41.5	448.9 ± 41.5	471.5 ± 42.7	496.9 ± 47.5	467.7 ± 46.4	<0.001
AIx (%)	12.5 ± 2.7	13.1 ± 3.1	13.4 ± 2.9	13.9 ± 3.3	13.4 ± 3.09	<0.001
SBP (mmHg)	110 ± 11.5	117.0 ± 15.5	123.8 ± 16.4	130.8 ± 17.2	122.6 ± 16.0	<0.001
DBP (mmHg)	71.9 ± 10.2	75.6 ± 11.1	80.6 ± 12.2	85.8 ± 12.9	79.8 ± 12.5	<0.001
Heart rate (beat/min)	83.4 ± 14.4	80.4 ± 11.2	80.8 ± 11.0	82.7 ± 11.6	81.0 ± 11.2	<0.001
Clinical history						
Diabetes mellitus	1 (2.70%)	84 (5%)	149 (6.1%)	81 (9.4%)	315 (6.30%)	<0.001
Hypertension	0 (0.00%)	94 (5.6%)	304 (12.4%)	179 (20.7%)	577 (11.5%)	<0.001
Ischemic heart diseases	0 (0.00%)	59 (3.5%)	97 (4%)	48 (5.5%)	204 (4.1%)	0.054
Myocardial infarction	0 (0.00%)	11 (0.7%)	28 (1.10%)	8 (0.9%)	47 (0.9%)	0.356
Fatty liver	0 (0.00%)	126 (7.5%)	428 (17.5%)	214 (24.7%)	768 (15.3%)	<0.001
Chronic lung disease	1 (2.7%)	44 (2.6%)	62 (2.5%)	50 (5.8%)	157 (3.1%)	<0.001
Stroke	0 (0.00%)	5 (0.3%)	9 (0.4%)	5 (0.60%)	19 (0.4%)	0.613
Kidney stone	7 (18.9%)	193 (11.6%)	342 (14%)	156 (18%)	698 (13.9%)	<0.001

Note: Values are presented as mean ± SD or *N* (%); Analysis by independent-samples *t*-test, Fisher's exact test (two-sided), or Chi-square test.
Abbreviations: AIx, augmentation index; DBP, diastolic blood pressure; MAP, mean arterial pressure; PWV, pulse wave velocity; SBP, systolic blood pressure.

TABLE 2 Pearson's correlation coefficients between pulse wave velocity parameters with bio-impedance indices

	PWV		AI		SBP		DBP		MAP	
Variable	*R*	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value	*r*	*p*-value
Body mass index	0.18**	<0.001	−0.02	0.065	0.28**	<0.001	0.23**	<0.001	0.28	<0.001
Body fat mass	0.16**	<0.001	−0.04	<0.001	0.26**	<0.001	0.19**	<0.001	−0.01	0.496
Soft lean mass	0.24**	<0.001	0.05	<0.001	0.19**	<0.001	0.23**	<0.001	0.01	0.397
Fat free mass index	0.15**	<0.001	0.01	0.25	0.18**	<0.001	0.19**	<0.001	0.17**	<0.001
Fat mass index	0.09**	<0.001	−0.05**	<0.001	0.21**	<0.001	0.12**	<0.001	−0.01	0.482
Visceral fat area	0.13**	<0.001	−0.05**	<0.001	0.24**	<0.001	0.15*	<0.001	−0.02\	0.09
Body cell mass	0.24**	<0.001	0.05**	<0.001	0.18**	<0.001	0.23**	<0.001	0.01\	0.29
50 kHz-whole body phase angle	0.08**	<0.001	0.05**	<0.001	0.04**	<0.001	0.11**	<0.001	0.10**	<0.001
Total body water	0.24**	<0.001	0.04**	<0.001	0.19**	<0.001	0.23**	<0.001	0.003	0.813
Intracellular water	0.23**	<0.001	0.05**	<0.001	0.18**	<0.001	0.22**	<0.001	0.01	0.494
Extracellular water	0.25**	<0.001	0.04**	<0.001	0.21**	<0.001	0.23**	<0.001	−0.008	0.587
Fat free mass	0.24**	<0.001	0.05**	<0.001	0.19**	<0.001	0.23**	<0.001	0.24**	<0.001
TBW/FFM	0.10**	<0.001	−0.001	0.96	0.13**	<0.001	0.10**	<0.001	0.23**	0.587
Waist–hip ratio	0.24**	<0.001	−0.02	0.111	0.29**	<0.001	0.25**	<0.001	−0.03**	0.008
Arm circumference	0.23**	<0.001	−0.006	0.67	0.30**	<0.001	0.27**	<0.001	0.003	0.81
Measured circumference of neck	0.25**	<0.001	0.01	0.191	0.28**	<0.001	0.26**	<0.001	−0.01	0.2
Measured circumference of chest	0.25**	<0.001	0.011	0.43	0.29**	<0.001	0.28**	<0.001	−0.007	0.65
Measured circumference of abdomen	0.28**	<0.001	−0.01	0.21	0.34**	<0.001	0.30**	<0.001	−0.01	0.39
Measured circumference of hip	0.21**	<0.001	−0.006	0.64	0.28**	<0.001	0.26**	<0.001	0.008	0.57

Note: **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
Abbreviations: AIx, augmentation index; DBP, diastolic blood pressure; MAP, mean arterial pressure; PWV, pulse wave velocity SBP, systolic blood pressure.

relationship between measured abdominal circumference and PWV ($r = 0.2$ $p < 0.001$), SBP ($r = 0.3$ $p < 0.001$), and DBP ($r = 0.3$ $p < 0.001$). Abdominal circumference had no significant correlation with AIx ($r = -0.01$ $p > 0.05$) and MAP ($r = -0.01$, $p > 0.05$) (Table 2).

Multiple regression analysis was then performed to identify the variables of anthropometric that were associated with PWV (Table 3). The study showed that age ($\beta = -0.06$, $p = 0.001$) was negatively associated with PWV. When adjusting for BMI, age, total body water (TBW), body fat mass (BFM), MAP, and CBP showed a significantly associated with PWV. But there was a negative association between BMI and PWV ($\beta = -0.05$, $p = 0.001$). Further model also did find negative association between BMI and PWV. As shown in model III, PWV was also significantly associated with BFM ($\beta = 0.1$, $p = 0.000$), MAP ($\beta = 0.2$, $p = 0.001$), and the waist–hip ratio (WHR) ($\beta = 0.1$, $p = 0.001$).

4 | DISCUSSION

Participants with overweight/obesity had higher risk of arterial stiffness as the gathered data showed increased SBP, DBP, MAP, AIx, and PWV in this group. As in this study population, the prevalence of some chronic diseases such as DM, hypertension, fatty liver disease, chronic lung disease, and kidney stones were significantly higher in individuals with overweight/obesity, these findings clearly determined that participants with overweight/obesity are more prone to some concerning comorbidities in Iranian population.

Scientists believe that people with higher BMI are more prone to stroke, myocardial infarction, and chronic kidney disease.[6,16] Recently, calculating BMI seems not enough accurate to estimate cardiovascular risk assessment as it does not evaluate sex, race, fat distribution, and body composition.[16] Thus, finding new methods and investigation techniques is crucial in this issue.

The current study was conducted in order to evaluate the association of anthropometric and non-invasive arterial stiffness parameters, including data on more than 5000 healthy individuals.

Overall, findings provided evidence to suggest that anthropometric indices had an association with PWV. Studies showed that both of these novel tests are reliable techniques in predicting cardiovascular outcome.[17] Recently, PWV has been recommended as a non-invasive measure to evaluate endothelial function and risk assessment for CVD all-cause mortality in unselected populations.[17,18]

TABLE 3 Determinants of PWV

Variable	*B*	β	*p*-value	R^2
Model 1				0.374
(Constant)	412.7		0.000	
Age	−0.3	−0.06	0.000	
Body mass index	24.7	0.03	0.000	
Model 2				0.651
(Constant)	296.1		0.000	
Age	−0.23	−0.04	0.001	
Body mass index	−3.4	−0.05	0.000	
Total body water	3.5	0.5	0.000	
Body fat mass	0.6	0.1	0.000	
Mean arterial pressure	2.1	0.3	0.000	
Central SBP	−0.3	−0.1	0.003	
Model 3				0.374
(Constant)	236.9		0.001	
Age	−0.3	−0.05	0.001	
Body mass index	−1.4	−0.02	0.001	
Total body water	0.8	0.1	0.600	
Body fat mass	0.6	0.1	0.000	
Mean arterial pressure	1.5	0.2	0.000	
Central SBP	−0.3	−0.1	0.000	
Waist–hip ratio	87.2	0.1	0.000	
Extracellular water	3.6	0.2	0.1	
Fat-free mass	0.7	0.1	0.4	

Abbreviations: PWV, pulse wave velocity; SBP, systolic blood pressure.

Fat distribution has always been a crucial factor to evaluate obesity effects on cardiovascular system. In this study, a positive correlation between abdomen circumference and SBP, DBP, and PWV was found which obviously showed the significant impact of aggregation of abdominal adipose tissue on CVD. A previous study by Zantine et al. showed individuals with high values of neck circumference had higher SBP, DBP, MAP, and PWV.[19] Similarly, current study found significant association between neck circumference and SBP, DBP, and PWV. However, the present survey found no significant correlation between neck circumference and MAP, which can be explained by age distribution of participants.

A previous Chinese study found that 50-kHz whole body phase angle is positively associated with PWV, AI, SBP, DBP, and MAP. Also, they found a significant correlation between visceral fat area (VFA) and PWV.[12] Likewise, the present survey showed an association between VFA and PWV, SBP, DBP, AI.

In parallel with various studies,[20,21] the current study found significant correlation between BFM, WHR, and MAP with PWV. Therefore, it seems that the visceral adipose tissue can be considered as a representative of endothelial dysfunction. Although BFM and WHR showed weak correlations, fat mass and WHR have been well known to be associated clinically with PWV.[22,23]

The current study demonstrated that SBP, DBP, AIx, and PWV were associated with TBW content including intercellular and extracellular water contents in the human body. Previous reports also suggested that hypertensive individuals had increased total water content compared to normotensive ones.[19,24]

Multiple regression analysis showed that age was negatively associated with PWV, while American authors illustrated positive association between PWV values and aging notably over 50 years.[25] The inconsistency in these results might be due to different ranges of participants' age. Similar results to ours have been reported in Brazilian population, showing a negative significant association between BMI and PWV.[26] This interesting finding might be stemmed from the mechanism of the obesity paradox. However, the correlation between obesity and PWV is still controversial and recent investigations suggested the better measurements of obesity than BMI including WHtR, waist circumferences, and sagittal abdominal diameters in abdominal obesity.[21] Results also indicated that WHR, fat mass Index, TBW, BFM, MAP, and central SBP were all significantly associated with PWV.

When clinical history was assessed among the subgroups according to BMI, this study showed the significant correlation between obesity and high blood pressure, DM, fatty liver disease, chronic lung disease and kidney stones. By the virtue of current findings, it can be assumed that anthropometric measurements and PWV are reliable predictive values in order to assess CVD risk. Moreover, these findings emphasized the role of lifestyle modification plans to control CVD risk and its inevitable consequences for public health.

In another study, reported that patients with obesity and hypertension had an increased water cell content,[27] however there are few studies evaluating directly correlation between body water including, TBW, intracellular water, and extracellular water and arteriosclerosis in healthy population.

Neck circumference used to be known as an index of upper-body subcutaneous adipose tissue distribution, whereas Ben Noun L et al. showed that it is positively related to most cardiovascular risk factors.[28]

This study had some limitations. First, its cross-sectional design and the inclusion of only Iranian participants limit its applicability to the general population. Further studies in other ethnic groups are needed to validate these findings. The strength of the study is that a large number of participants were included, and a population-based cohort design was performed.

5 | CONCLUSION

The prevalence of some chronic disease such as DM, hypertension, fatty liver disease, chronic lung disease and also kidney stones were significantly higher in participants with overweight/obesity. BMI, BFM, WHR, measured circumference of abdomen and neck, VFA, TBW, 50-kHz whole body phase angle were positively correlated with PWV. Augmentation index had no significant correlation with BMI, arm circumference, and measured circumference of hip, abdomen, and arm.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Sahar Sobhani, Saeid Eslami, and Majid Khadem-Rezaiyan designed the study. Saba Vakili, Reihaneh Aryan, and Maryam Alinezhad-Namaghi performed the measurements regarding arterial stiffness. Saeid Eslami were involved in planning and supervised the work. Sahar Sobhani, Dina Javid Jam, and Majid Khadem-Rezaiyan performed the data analysis. Sahar Sobhani, Saba Vakili, and Reihaneh Aryan drafted the manuscript and designed the tables. All authors discussed the results and critically reviewed the content of this article and have approved the current final version.

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