Nigerian Medical Journal
NIGERIA MEDICAL ASSOCIATION
Print ISSN 0300-1652, E-ISSN 2229-774X

Original Article

Association of BMI Grading with Aortic Pulse Wave Velocity and Augmentation Index in a Population of West India

Jayesh Dalpatbhai Solanki [1], Pankti Prathmesh Bhatt [1], Param J Kakadia[1],

[1]Department of Physiology, Govt Medical College, Bhavnagar, Bhavnagar University Campus, Bhavnagar, Gujarat, India.

Abstract

Background: BMI is graded differently in Asians, and its association with pulse wave analysis (PWA) based arterial stiffness (AS) parameters are unknown in the Indian population. We studied these AS parameters in relation to BMI grading as per ESI (Endocrine Society of India) for association, if any.

Methodology: This is a secondary pooled analysis of previously published data of normal (n=1186), diabetics (n=328), hypertensives(n=309), and diabetic hypertensives(n=401). Oscillometric PWA (Mobil-o-graph, IEM, Germany) was used to derive aortic BP (aBP), aortic pulse wave velocity (aPWV), augmentation index (AIx), and reflection %. All participants in each group were divided into BMI-based subgroups as per the ESI criteria for Indians. PWA parameters were compared among BMI-based subgroups in each of the four study groups.

Results: Aortic pressures, AIx, aPWV, and Ref% were significantly associated with BMI grading only in the normal subgroup and not in the other three groups with at least one of either diabetes or hypertension. In the multivariate linear regression model, BMI-based grading was not associated with aPWV or AIx after adjusting for gender, age, mean blood pressure, heart rate, and presence of diabetes and/or hypertension.

Conclusion: It suggests arterial stiffness to be a poorly BMI-dependent parameter and calls for more studies for its consolidation.

Keywords: Arterial stiffness, body mass index, diabetes mellitus, hypertension, pulse wave velocity

***Correspondence:** Dr. Solanki Jayesh Dalpatbhai, Assistant professor in the Physiology department, Dept of Physiology, Fourth floor, GMC, Jail Road, Bhavnagar, Gujarat.364001, **E-mail address:** drjaymin_83@yahoo.com

How to Cite: Solanki JD, Bhatt PP, Kakadia PJ. Association of BMI grading with aortic pulse wave velocity and augmentation index in a population of west India. Niger Med J 2025; 67 (1): 2615-2622. https://doi.org/10.71480/nmj.v67i1.1190

Quick Response Code:

Introduction

Obesity, the modern pandemic, takes a heavy toll on cardiovascular health, accelerating vascular ageing.[1] This manifests as increased arterial stiffness(AS). Aortic pulse wave velocity (aPWV) and augmentation index at heart rate 75(AIx@75) are two such AS parameters measured by non-invasive pulse wave analysis (PWA). Few PWA studies [2,3,4,5] have been published in the normal, diabetic, and/or hypertensive Indian population. BMI is a routinely measured obesity parameter whose grading is suggested by ESI for the Indian population. The effect of BMI grading based on ESI criteria on the distribution of aPWV and AIx@75 is not documented & we set out for the same.

Methods

Study population: This is a secondary pooled cross-sectional analysis of our data collected during 2016 to 2018. Measurement protocols and instruments were identical in all datasets, with no inter-study heterogeneity with reference to study methods. They were recruited from the same geographic region and differed by the presence and/or absence of diabetes and/or hypertension. For this sub-analysis, we included participants' data from four previously published studies[2,3,4,5] on non-diabetic non-hypertensives (n=1186), diabetic non-hypertensives(n=328), non-diabetic hypertensives(n=309), and diabetic hypertensives(n=401), which were separately considered as four different groups for data analysis. This sub-analysis was covered under ethical approval of these original studies of our institution numbered IRB(HEC) 577/2015 dated 26 /11/2015 and IRB(HEC) 596/206 dated 23/05/2016. Each of the four groups was further stratified into five subgroups based on BMI as follows: B1: BMI <18.5 kg/m^2, B2: BMI 18.5-22.9 kg/m^2, B3: BMI 23-24.9 kg/m^2, B4: BMI 25-29.9 kg/m^2, B5: BMI ≥ 30 kg/m^2

PWA -Instrument and Measurement protocol:

We used a portable, personal computer attached, calibrated, and validated instrument, Mobil-O-Graph (IEM Gmbh, Stolberg, Germany) of the Physiology department to record the brachial pulse wave. It undergoes oscillometric pressure PWA as per the protocol designed by the European Society of Hypertension (ESH). A blood pressure cuff of appropriate size (mid-arm circumference: 20–24 cm = small size, 24–32 cm = medium size, 32–38 cm = large size) was chosen based on measured mid-arm circumference and applied to the left arm using a standard protocol. All readings were taken after resting for 10 min, in the post absorptive phase, while subjects avoided smoking or alcohol for 12 hours before measurement, in a calm room without external influences, and avoiding arm movement. Pressure oscillations are generated by brachial arterial pulsation, which is transmitted to the brachial blood pressure cuff and measured by the transducer to be fed into the microprocessor. Computerized software records the pulse wave of the brachial artery to derive the central aortic pulse wave by avalidated, generalized transfer factor. It further undergoes point-based and area-based analysis by computer to derive various cardiovascular parameters.

aPWV and AIx@75: aPWV – It is the speed at which the pulse wave travels in the aortic wall and is calculated by point-based analysis of the aortic pulse wave derived from brachial pulse wave recordings. It gives a measure of central arterial stiffness. Most other PWA methods use regional arterial stiffness like brachial-ankle PWV, but Mobil-o-graph gives aortic stiffness, which is the most direct parameter affecting ventricular functioning. With vascular ageing, there is reduced aortic compliance that is measured as increased stiffness, giving raised aPWV.

AIx@75: It is derived from augmentation pressure (AP) and PP of a pulse wave. Pulse wave is a summation of the forward wave (producing the first systolic peak) and the reflected wave (producing the second peak). An increase in amplitude of pulse wave due to reflection of pulse wave is known as pulse augmentation, and its contribution to the pulse wave amplitude is known as AP. Moreover, the percentage of pulse wave amplitude due to AP is known as AIx. AIx = AP/PP × 100. AIx is dependent on HR, so it is corrected for same, and Mobil-o-graph gives it at HR 75, the final parameter being AIx@75. AIx@75 is a measure of peripheral arterial stiffness. The stiffer the peripheral arteries, early and more augmented will be the reflection from the periphery. It increases AP and AIx, which is a measure of extra afterload that inflicts ventricle.

Statistical Analysis

All data were entered into an Excel spreadsheet and sorted separately for each of four groups, and calculations were accomplished using statistical software GraphPad InStat 3 software (demo version, free software of GraphPad Software, Inc., California, USA). The distribution of parameters was compared between BMI-based groups B1 to B5 for each of the four study groups. For continuous data, ANOVA was used for parametric distribution, and Kruskal-Wallis was used for non-parametric distribution. For categorical data, the Normality test or Chi-Square test was used. Multiple linear regressions were run to check the association between AS parameters and BMI after statistical adjustment of confounders. For all calculation statistical significance was set as p value less than 0.05.

Distribution of BMI-based subgroups in the four study groups is as follows:

Group	B1	B2	B3	B4	B5	Total
Non diabetic non hypertensive	141	428	238	294	85	1186
diabetic non-hypertensive	4	68	66	76	14	328
Non diabetic hypertensive	9	89	81	108	21	309
Diabetic hypertensive	7	75	87	177	55	401

Results

BMI-based non-diabetic non-hypertensive participants' subgroups (n=1186) had a significant difference in age and gender distribution. HR was comparable between groups, but other aortic BP, aPWV, and AIx were higher across the groups B1 to B5, having statistical significance with group 1and 5 being more consistently responsible for the overall difference in post hoc test.[Table 1]

Table 1 Comparison of study parameters in non-diabetic non-hypertensive participants' subgroups stratified by ESI-based BMI grades (total n=1186)

Para meter	Group 1 B1(n=141)	Group 2 B2(n=428)	Group 3 B3(n=238)	Group 4 B4(n=294)	Group 5 B5(n=85)	P value Post hoc Test
Age	25.52 ±10. 79	35.12 ±14.04	39.88 ±11.36	39.09 ±11.36	42.79 ±10.04	<0.001 , all except B3-4,B3-5 ,B4-5
Male /female	76/ 65	234/ 194	132/ 106	121/ 173	19/ 66	<0.0001
HR	88.85 ±13.52	88.41 ±14.10	88.28 ± 13.71	89.35 ±13.93	90.94 ±14.07	0.53
aSBP	105.95 ±11.62	111.31 ±13.44	115.60 ±13.66	114.76 ±14.04	120.02 ± 14.04	<0.001 , all except B3-5 ,B4-5
aDBP	78.85 ±10.61	81.29 ±10.77	83.47 ±11.31	83.16 ±10.58	85.51 ±12.50	<0.001, B1-3, B1-4, B1-5, B2-5
aPP	28.02 ±7.92	30.26 ±8.66	32.43 ±9.52	31.83 ±8.71	34.4 ± 9.60	<0.001, B1-3, B 1-4, B1-5, B2-5

Niger Med J 2025;67(1): 130 - 137, **ISSN**: 0300-1652, **E-ISSN**: 2229-774X, **Publisher**: Nigerian Medical Association. Jan. – Feb. **2026**

aPWV	5.13 ±0.91	5.91 ±1.25	6.39 ±1.25	6.25 ±1.15	6.76 ±1.29	<0.001 , all except B3-4,B3-5
AIx @75	29.80 ±10.98	29.99 ±10.49	29.74 ±10.07	30.59 ±10.33	34.14 ±10.39	0.009, B1-5, B2-5, B3-5, B4-5
Ref%	59.23 ±8.51	62.07 ±8.11	63.81 ±7.80	63.69 ±7.07	64.0 ±7.23	<0.001 , all except B3-4,B3-5 ,B4-5

BMI-based diabetic non-hypertensive participants' subgroups (n=328) were comparable for age, gender distribution, and HR, and there was no statistically significant difference in aortic BP and AS between them. BMI-based subgroups (n=309) in diabetic non-hypertensive participants had comparable age, gender distribution, and HR without a statistically significant difference in aortic BP and AS between them. Diabetic hypertensive participants' subgroups (n=401) based on BMI had age, gender distribution and HR comparable and there was no statistically significant difference of aortic BP(except aPP) and AS between them[Table 2]

Table 2 Comparison of study parameters in diseased sub groups stratified by ESI based BMI grades

Diabetic non-hypertensive participants				
Para meter	**Group 1 B1+B2(n=72)**	**Group 2 B3(n=66)**	**Group 3 B4+B5(n=90)**	**P value**
Age	49.94 ±13.74	53.35 ±15.18	51.5 ±8.97	0.28
Male/female	42/30	35/31	36/54	0.05
HR	92.01±14.37	89.97±15.21	92.83±14.26	0.47
aSBP	123.04±16.34	123.98±15.91	125.25±15.71	0.67
aDBP	88.54±9.96	88.58±12.20	87.46±10.20	0.75
aPP	34.5±11.11	35.55±9.14	38.11±12.22	0.10
aPWV	7.74±1.93	7.75±1.17	7.75±1.12	0.99
AIx@75	35.19±11.61	30.94±12.63	34.64±10.65	0.06
Ref%	64.01±8.24	65.61±5.75	66.5±8.43	0.12
Non-diabetic hypertensive participants				
Para meter	**Group 1 B1+B2(n=98)**	**Group 2 B3(81)**	**Group 3 B4+B5(n=129)**	**P value**
Age	48.96±9.51	48.75±7.94	47.70±7.60	0.48
Male/female	43/55	38/43	63/66	0.75
HR	88.21±15.81	86.79±15.12	88.62±14.15	0.68
aSBP	127.94±19.39	128±15.97	128.40±17.41	0.97
aDBP	91.16±13.98	90.81±13.54	91.92±14.09	0.83
aPP	36.78±12.38	37.25±11.87	36.47±10.84	0.90
aPWV	7.66±1.31	7.52±0.92	7.42±1.01	0.25
AIx@75	33.70±11.62	32.58±11.62	32.88±10.17	0.77
Ref%	65.66±7.81	65.46±7.69	65.08±7.19	0.84
Diabetic hypertensive participants				
Para meter	**Group 1 B1+B2(n=82)**	**Group 2 B3(n=87)**	**Group 3 B4+B5(n=232)**	**P value**
Age	51.02±8.61	52.31±7.39	53.63±9.11	0.054
Male/female	46/36	53/34	109/123	0.27
HR	93.35±16.66	89.69±14.11	91.37±13.95	0.27

aSBP	128.40±17.17	125.82±17.57	128.72±19.36	0.42
aDBP	91.28±11.80	90.74±12.38	88.86±13.92	0.27
aPP	37.00±11.76	35.08±11.63	39.22±13.99	0.034*
aPWV	7.97±1.29	7.83± 1.12	8.17± 1.33	0.09
AIx@75	36.13±12.09	32.06±11.54	34.73±11.75	0.07
Ref%	66.30±6.62	64.71±6.25	66.06±7.47	0.25

In each group separately, multiple linear regressions were run to check association between aPWV or AIx and BMI after adjusting for age, gender, HR, MBP, diabetes and hypertension. Most associations were small and statistically not significant, except the AIx to BMI correlation in the B2 group. [Table 3]

Table 3 Multivariate linear regression of aPWV or AIx with BMI adjusted for age, gender, MBP, HR , Diabetes and hypertension

Group	**aPWV**			**AIx**		
	β	**P value**	**95% C. I.**	**β**	**P value**	**95% C. I.**
B1	0.03	0.29	-0.02,0.08	-0.82	0.13	-1.87,0.24
B2	0.05	0.87	-0.52,0.61	-0.05	**0.004**	-0.08,-0.02
B3	0.07	0.17	-0.03,0.18	-0.05	0.95	-1.50,1.40
B4	-0.02	0.48	-0.07,0.03	0.06	0.82	-0.46,0.57
B5	0.02	0.20	-0.01,0.06	0.09	0.66	-0.31,0.57

Discussion

Despite being the simplest measure for obesity, BMI owes its demerits [6].BMI grading has a variable association with some cardiovascular screening tools, of which we selected arterial stiffness and augmentation index. We found no relationship between BMI grade and AS parameters in a moderately large sample of the Indian population grouped separately by the presence or absence of diabetes and /or hypertension. AS is not a totally BP-dependent parameter as previously published [2,3,4,5], and its lack of correlation with BMI suggests it as an add-on parameter to infer about in the population for vascular ageing, which is a major cardiovascular health determinant.

Age, gender distribution, heart rate, and concomitant diabetes or hypertension are confounders that can affect the BMI-based comparison of AS [2,3,4,5]. The study population was divided into four groups based on the presence and /or absence of diabetes and/or hypertension, as these two are the major factors affecting aortic hemodynamics and AS.HR was comparable across all comparison groups while sub-grouping them based on BMI grading. This is significant as these parameters are HR dependant, and without their confounding effect, they can be better compared. In 3 out of 4 groups, age and gender were comparable, negating these biases. Rather, it's possible that the difference in AS and aortic blood pressure in BMI-based subgroups in the non-diabetic non-hypertensive groups was due to differences in age and gender distribution in the five groups.

This lack of BMI grade to AS relationship can be due to: 1) disparity of BMI grade cut offs for Asians,[6] 2) BMI infers to general not the visceral or central obesity[7] with later being more strongly associated to AS[8], 3) Indian ethnicity being more vulnerable to cardiovascular diseases[9] even at low BMI, 4) both BMI and AS inferring to different facet of health with complex cross talk, 5) mean age of study population in three of four study groups was higher on average which may blunt BMI –AS relationship[10] 6) Three out of four groups had participants treated for diabetes and \or hypertension which itself can affect both BMI and AS[3,4,5]

The BMI to AS relationship was tested after adjusting for age, gender[11], MBP[12], HR[13], diabetes[14], and hypertension[15], which are six common confounders for the same. Cardiac adipose tissue is a key player in cardiometabolic disease, as recently reported [16], that infers more discrete than BMI. Abdominal obesity and low HDL-c have been suggested as potent, independent predictors for cardiovascular events, outperforming traditional markers like BMI.[17] As recently highlighted, weight-based bias and stigma are major obstacles for effective prevention and treatment of obesity, and inference beyond general BMI is needed.[18] In a cross-sectional study of a large middle-to-older-aged cohort, waist hip ratio was the strongest adiposity marker, which correlated with cardiometabolic risk[19], and the same can be used for future studies. In another study, higher arterial stiffness and 10-year cardiovascular risk were seen associated with normal-weight visceral obesity.[20] Above this, ethnicity has been reported to be associated with central but not local arterial stiffness, a similar scenario to that of BMI. Conversely, ethnicity seems to modify associations between cardiovascular risk factors and central arterial stiffness. [21]

BMI itself has its own limitations that fall short of its inference about visceral or central obesity[6], which is better associated with cardiovascular risk factors and diseases.BMI grading is also different in Asians, and its grading-based association with various cardiovascular risk factors, like AS, has given inconsistent results in light of the obesity paradox[21]. It also suggests that parameters like waist circumference, waist-hip ratio, visceral fat, and qualitative body fat can be better than BMI and warrant study for the same.AS parameters are proven to be beyond BP screening tools, more stable than BP itself, and the result of the culmination of multiple risk factors on vascular health.[2,3,4] They can complement the vascular ageing study better than BP. The utility of PWA-based AS parameters can be further appreciated as they are also not BMI dependent, as suggested by our study, and after age and gender matching, their utility gets even more pronounced.

Our study was limited by single-point measurements, presence of confounders, lack of vertical follow-up, lack of direct measures of visceral fat, single-time-point measurements, treatment effects (antihypertensives, statins, antidiabetics), potential survivor and selection bias. Yet, it hints at AS to be a BMI independent parameter and calls for more studies to its affirmation with a larger sample, more parameters of obesity included, vertical follow-up, and interventions.

Funding

No financial support/ funds or grants were received for the research and/or publication.

Declaration of competing interest

Authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1. Ruperez C, Madeo F, de Cabo R, Kroemer G, Abdellatif M. Obesity accelerates cardiovascular ageing. Eur Heart J 2025;46(23):2161-85.

2. Solanki JD, Mehta HB, Shah CJ. Aortic pulse wave velocity and augmentation index@ 75 measured by oscillometric pulse wave analysis in Gujarati nonhypertensives. Vasc Investig Ther 2018;1(2):50-5.

3. Solanki JD, Munshi HB, Mehta HB, Shah CJ. Central hemodynamics and arterial stiffness in Gujarati diabetics not receiving any antihypertensive: A case–control study based on oscillometric pulse wave analysis. J Family Med Prim Care 2019;8(4):1352-8.

4. Solanki JD, Mehta HB, Panjwani SJ, Munshi HB, Shah CJ. Central hemodynamics and arterial stiffness by oscillometric pulse-wave analysis in treated Gujarati euglycemic hypertensives: A case-control study. J Family Med Prim Care 2019;8(6):2047-54.

5. Solanki JD, Panjwani SJ, Patel RK, Bhatt DN, Kakadia PJ, Shah CJ. Assessment of arterial stiffness, brachial haemodynamics, and central haemodynamics in diabetic hypertensives: a pulse wave analysis-based case-control study from an urban area of west India. Pulse 2021;9(3-4):89-98.

6. Bajaj SS, Zhong A, Zhang AL, Stanford FC. Body mass index thresholds for Asians: a race correction in need of correction?. Ann Intern Med 2024;177(8):1127-9.

7. Riaz M, Lodhi S. Beyond BMI: Exploring obesity trends in the South Asian region. Obes Pillars 2025;13:100156.

8. Zhao L, Zhou X, Chen Y, Dong Q, Zheng Q, Wang Y, et al. Association of visceral fat area or BMI with arterial stiffness in ideal cardiovascular health metrics among T2DM patients. J Diabetes 2024;16(1):e13463.

9. Jan B, Dar MI, Choudhary B, Basist P, Khan R, Alhalmi A. Cardiovascular diseases among Indian older adults: A comprehensive review. Cardiovasc Ther 2024;2024(1):6894693.

10. Kim HJ, Shin JH, Kim BS, Kang J, Lee H, Sung KC. Age-related annual changes in arterial stiffness in healthy adults: Insights from a large Korean cohort study. Atheroscler 2024;398:118592.

11. Sultan SR. Gender differences in aortic blood pressure, arterial stiffness, and cerebral blood flow in healthy adults: A STROBE-compliant cross-sectional observational study. Med 2025;104(23):e42717.

12. Quarti-Trevano F, Cuspidi C, Dell'Oro R, Ambrosino P, Grassi G. Association between arterial stiffness, high blood pressure, and hypertensive phenotypes: insights from the PAMELA study. J Clin Med 2025;14(7):2230.

13. Sista A, Ittermann T, Gross S, Markus MR, Stone K, Stoner L, et al. Sex and resting heart rate influence the relation between arterial stiffness and cardiac structure and function–insights from the general population. J Hum Hypertens 2025:;39(4):254–61.

14. Partalidou S, Patoulias D, Pantekidis I, Kefas A, Doumas M, Gkaliagkousi E, et al.The cross-talk between arterial stiffness and microvascular complications in diabetes mellitus: a systematic review of the literature. J Diabetes Metab Disord 2025;24(2):144.

15. Aristizábal-Ocampo D, Álvarez-Montoya D, Madrid-Muñoz C, Fernández-Ruiz R, Gallo-Villegas J. Circulatory phenotypes in hypertension identified by 24-h ambulatory blood pressure monitoring. J Hypertens 2026;44(1):100-8.

16. D'Elia S, Luisi E, Solimene A, Serpico C, Morello M, Titolo G, et al.Targeting Obesity in Cardiovascular Disease Management: Cardiac Adipose Tissue Is a Real Biomarker!. Targets 2025;3(2):17.

17. De Matteis C, Petruzzelli S, Graziano G, Novielli F, Di Buduo E, Cantatore S,et al. Improving cardiovascular risk stratification: the role of abdominal obesity in predicting MACEs. Cardiovasc Diabetol 2025 ;24(1):328.

18. Rubino F, Cummings DE, Eckel RH, Cohen RV, Wilding JP, Brown WA, et al. Definition and diagnostic criteria of clinical obesity. Lancet Diabetes Endocrinol 2025;13(3):221-62.

19. Montoya Castillo M, Martínez Quiroz WD, Suarez-Ortegón MF, Higuita-Gutiérrez LF. Waist-to-height ratio, waist circumference, and body mass index in relation to full cardiometabolic risk in an adult population from Medellin, Colombia. J Clin Med 2025; 14(7):2411.

20. Huang Y, Hu Y, Bao B. Relationship of body mass index and visceral fat area combination with arterial stiffness and cardiovascular risk in cardiovascular disease-free people: NHANES (2011–2018). Endocr Connect 2023; 12(11):e230291.

21. Van der Sluijs KM, Thannhauser J, Visser IM, Nabeel PM, Raj KV, Malik AE,et al. Central and local arterial stiffness in White Europeans compared to age-, sex-, and BMI-matched South Asians. PloS One 2023;18(8):e0290118.