

Assessment of Impaired Aortic Distensibility in Hypertensive Patients Undergoing Cardiac Computed Tomography

Mahmood A. A. Thabit *, Mamdouh H. Eltahan, Ashraf A. Abdelfattah

Department of Cardiology, Faculty of Medicine for Boys, Al-Azhar University, Cairo, Egypt

Abstract

Background: Arterial elasticity is an essential feature of vessels that plays a role in hypertension, which is considered a major modifiable risk factor for developing cardiovascular diseases. Multi-slice cardiac computed tomography angiography (CTA) has evolved as a noninvasive technique for the evaluation of aortic distensibility and localized stiffness, as well as atherosclerotic coronary artery diseases (CAD).

Aim: To evaluate aortic distensibility impairment and aortic stiffness measured by cardiac CTA and their relation with hypertension and the development of atherosclerotic CAD.

Patients and methods: 100 hypertensive patients and 100 normotensive patients were included in our case-control study. All these patients underwent brief history taking, clinical examination, standard electrocardiogram (ECG), routine laboratory investigations, and multi-slice cardiac CTA. Aortic distensibility index (ADI) and pulsed wave velocity (PWV) were estimated by measuring maximum (systolic and diastolic) cross-sectional area (CSA) of the ascending aorta (AAo) and blood pressure (systolic and diastolic) measurements using previously published equations. Coronary calcium scoring and coronary plaque burden assessment were done.

Results: The hypertensive patients had lower ADI and higher PWV than normotensive patients, with negatively correlated ADI and positively correlated PWV with elevated systolic blood pressure. Multivariable analysis revealed that ADI was associated more significantly with age and hypertension. ADI and PWV were significantly correlated with the severity of CAD.

Conclusion: Aortic distensibility impairment and aortic stiffness are well associated with hypertension and with the severity of atherosclerotic CAD. Multi-slice CTA provides a good measure for ADI and PWV, which can be useful in predicting hypertension and atherosclerotic CAD.

Keywords: Aortic Distensibility; Aortic Stiffness; Hypertensive Patients; Coronary Artery Disease; Cardiac Computed Tomography

1. Introduction

Arterial hypertension is considered the major modifiable conventional risk factor for developing different cardiovascular diseases (CVD).¹ On the other side, the elasticity is an essential functional feature of the arterial wall. A reduction in the elasticity of the ascending aorta was noted prior to the development of morphological abnormalities in pre-hypertensive individuals.² ADI was suggested to be a potential biomarker to act as a noninvasive control in interventional hypertension trials,³ and arterial PWV evaluation is recommended by the European Society of Hypertension (ESH)

and European Society of Cardiology (ESC) guidelines for the management of hypertension.¹

Aortic distensibility is also associated with atherosclerotic CAD, and the researchers claim that routine evaluation of aortic stiffness during cardiac CTA can improve the strategies of risk stratification and monitoring the progression of CVD.⁴ Also, assessment of aortic stiffness by measurement of PWV was suggested to be clinically useful in decreasing the number of unnecessary angiographies.⁵

The study aimed to evaluate aortic distensibility impairment and aortic stiffness measured by cardiac CTA and their relation with hypertension and the development of atherosclerotic CAD.

Accepted 15 April 2025.
Available online 30 June 2025

* Corresponding author at: Cardiology, Faculty of Medicine for Boys, Al-Azhar University, Cairo, Egypt.
E-mail address: mahmood.a.thabit@gmail.com (M. A. A. Thabit).

<https://doi.org/10.21608/aimj.2025.446620>

2682-339X/© 2024 The author. Published by Al-Azhar University, Faculty of Medicine. This is an open access article under the CC BY-SA 4.0 license (<https://creativecommons.org/licenses/by-sa/4.0/>).

2. Patients and methods

A case-control study was done on 100 hypertensive patients (the case group) and 100 normotensive patients (the control group) who underwent coronary CTA in Islamic Cardiac Center—Al-Azhar University from June 2023 to March 2024. All these patients underwent brief history taking, clinical examination, standard ECG, routine laboratory investigations, and multi-slice cardiac CTA.

Inclusion criteria: Adult patients presented with chest pain, jaw/shoulder pain, epigastric pain, or dyspnea that worsened with effort (patients had low to intermediate pretest probability according to 2019 ESC guidelines on the diagnosis and management of chronic coronary syndrome) or had new ECG abnormalities with unequivocal stress tests.

Exclusion criteria: Patients had acute coronary syndrome, cardiac arrhythmia, pacemaker pacing, renal dysfunction (eGFR <30 mL/min/1.73 m² or serum creatinine > 1.5 mg/dl), or had difficulties in CT performing (like inadequate breath holding), a history of allergy to contrast media, a history of open-heart surgery/coronary artery stenting, and post-valve replacement were excluded from the study.

Blood pressure (BP) measurements: Patients were positioned in certain conditions according to the 2021 ESH guidelines for an optimal office BP measurement,⁶ and three measurements (2-minute intervals) were taken before they went to coronary CTA by at least half an hour, and the average of these measurements was used to define the patient's representative values.

Classification of patients: Patients who had systolic BP ≥ 140 mmHg and/or a diastolic BP ≥ 90 mmHg, or were known hypertensive and controlled by medications, are classified as the hypertensive (case) group, while patients who had systolic BP < 140 mmHg and a diastolic BP < 90 mmHg without a history of hypertension are classified as the normotensive (control) group.

Cardiac CT angiography: The multi-detector dual-source energy CT technology (Toshiba Aquilion PRIME 160-slice CT Scanner, Japan) was employed for the selected patients after their good preparation according to the protocol recommended by the Society of Cardiovascular Computed Tomography (SCCT).⁷ A non-contrast-enhanced CT scan for coronary calcium scoring preceded the contrast-enhanced, where the CT scanning was performed with retrospective ECG-gated acquisition spiral mode, and the CTA images were reconstructed into different phases of the cardiac cycle (5%, 10%, ... 95%) by the acquisition of thin slice sections (0.5 mm) depending on the R-R interval of the ECG. A

three-dimensional workstation software (Vitrea® version 6.8.0; Toshiba Medical Systems Group Company) was used for image reconstruction to quantify areas of the ascending aorta and to evaluate coronary arteries at different phases of the cardiac cycle.

Aortic measurements: Measurements of maximum systolic and diastolic AAO CSA were done, measured manually at 15 mm above the left main coronary ostium and perpendicular to the longitudinal axis of the ascending aorta using both axial and coronal views, and at both systolic (35%-45%) and diastolic (75%-85%) phases of the cardiac cycle, like that was done in Ahmadi et al. study,⁸ Figure 1.

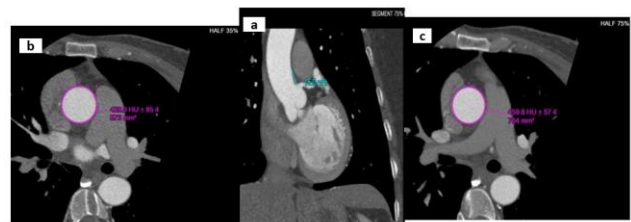


Figure 1. CT aortic measurement: a) coronal view showing longitudinal section of ascending aorta; b) axial view showing cross-section of aorta at diastolic phase (75% of cardiac cycle); c) axial view showing cross-section of aorta at systolic phase (35% of cardiac cycle).

Estimation of ADI: Aortic distensibility was derived by a previously published formula⁹:

$$\text{Distensibility} = \frac{(SA - DA)}{DA (SBP - DBP)} \times 10^3$$

(SA & DA are systolic & diastolic areas; SBP & DBP are systolic & diastolic BP)

Estimation PWV: It was calculated from aortic distensibility using the Bramwell-Hill equation¹⁰:

$$PWV = \frac{3.57}{\sqrt{\text{Distensibility}}}$$

Coronary calcium scoring: A non-contrast-enhanced CT scan for coronary artery calcium (CAC) score preceded the contrast-enhanced scan, and calcium deposits in coronary arteries could be seen in different images of the heart, and the amount of calcium deposits was measured by the Agatston score, as illustrated in previous studies.¹¹

Coronary CTA: An atherosclerotic coronary plaque burden assessment was done through plaque type identification (no plaque, soft plaque, calcific plaque, or mixed plaque), coronary lumen stenosis grading (grade 0 = no stenosis; grade 1 < 50% stenosis; grade 2 = 50–69% stenosis; grade 3 ≥ 70% stenosis), and calculation of both segment-involvement score (SIS) and segment-stenosis score (SSS), as described in previous studies.¹²

Statistical analysis: Statistical Package for the

Social Sciences (SPSS version 26.0, IBM Corporation) software was used for collecting and analyzing data. Quantitative variables were assessed for normality of data distribution by using the histogram and Kolmogorov-Smirnov test, expressed as mean with standard deviation (SD) for normally distributed variables and as median with range for not normally distributed variables, while the categorical variables were expressed as frequency. Comparisons of categorical variables between the two groups were performed by using the Chi-square test. Continuous variables between the two main groups were compared using an independent samples T-Test (for normally distributed variables) and a Mann-Whitney U test (for not normally distributed/ordinal variables). Pearson's correlation analysis was used for normally distributed continuous variables, while Spearman's correlation analysis was used for not normally distributed continuous variables. Univariate and multivariable linear regression analyses were used to determine the connection of conventional cardiovascular risk factors with both ADI and PWV. A p-value < 0.05 means a statistically significant result, while a p-value > 0.05 is considered a non-significant result. The lower and upper values of the 95% CI (confidence interval) of correlation and regression coefficients were expressed to confirm the significant result that was determined by the P value.

3. Results

Our results expressed the means of age, diabetes mellitus, dyslipidemia, systolic BP, diastolic BP, and pulse pressure (PP) among the hypertensive group were higher than that of the normotensive one with a statistically significant difference between both groups (P value < 0.001), while there were statistically non-significant differences between both groups regarding gender, smoking, family history of ischemic heart disease (IHD), main complaint, heart rate, and ECG findings, as shown in Table 1.

Table 1. Demographic and clinical data among hypertensive and normotensive groups

	HYPERTENSIVE GROUP (100 PATIENTS)	NORMOTENSIVE GROUP (100 PATIENTS)	P VALUE
AGE:	52.26 (6.79)	43.66 (8.80)	< 0.001
▪ MEAN (SD):	36 – 69	28 – 65	
▪ RANGE:			
GENDER:	21	32	0.078
▪ MALE:	79	68	
▪ FEMALE:			
DIABETES MELLITUS:	42	10	< 0.001
▪ DIABETIC	58	90	
▪ NON- DIABETICS:			
DYSLIPIDEMIA:	60	35	< 0.001

▪ DYSLIPIDEMIC:	40	65	
▪ NON- DYSLIPIDEMIC:			
SMOKING:			0.809
▪ SMOKER:	10	9	
▪ NON-SMOKER:	90	91	
FAMILY HISTORY OF IHD:	17	12	0.315
▪ POSITIVE:	83	88	
▪ NEGATIVE:			
MAIN COMPLAINT:			0.637
▪ CHEST PAIN:	89	91	
▪ DYSPNEA:	11	9	
HEART RATE:	72.07 (9.91)	73.23 (8.73)	0.381
▪ MEAN (SD):	50 – 95	51 – 91	
▪ RANGE:			
SYSTOLIC BP:			< 0.001
▪ MEAN (SD):	139.85 (16.23)	120.80 (8.37)	
▪ RANGE:	110 – 180	100 – 130	
DIASTOLIC BP:	89.25 (9.62)	78.90 (5.93)	< 0.001
▪ MEAN (SD):	70 – 110	60 – 90	
▪ RANGE:			
PULSE PRESSURE:			< 0.001
▪ MEAN (SD):	50.60 (8.60)	41.90 (4.65)	
▪ RANGE:	40 – 80	30 – 50	
ECG FINDINGS:			0.558
▪ NORMAL ECG:	83	86	
▪ ABNORMAL ECG:	17	14	

The means of AAO CSA at maximum systole and at maximum diastole among the hypertensive patient group were higher than that of the normotensive one, with a statistically significant difference between both groups (P value = 0.011 and P value < 0.001, respectively). Also, the mean PWV in the hypertensive patient group was higher than in the normotensive one, while the mean ADI was lower in the hypertensive group compared to the normotensive group, and these differences were statistically significant between both groups (P value < 0.001), Table 2 and Figure 2.

Table 2. CT aortic measurements among hypertensive and normotensive groups

	HYPERTENSIVE GROUP (100 PATIENTS)	NORMOTENSIVE GROUP (100 PATIENTS)	P VALUE
AAO CSA (CM ²) AT MAXIMUM SYSTOLE:	8.21 (1.60)	7.58 (1.81)	0.011
▪ MEAN (SD):	5.20 – 12.66	3.94 – 12.92	
▪ RANGE:			
AAO CSA (CM ²) AT MAXIMUM DIASTOLE:	7.69 (1.59)	6.77 (1.82)	< 0.001
▪ MEAN (SD):	4.79 – 12.36	3.37 – 12.24	
▪ RANGE:			
ADI:			< 0.001
▪ MEAN (SD):	1.44 (0.75)	3.10 (1.38)	
▪ RANGE:	0.43 – 3.29	0.88 – 6.71	
PWV:			< 0.001
▪ MEAN (SD):	3.32 (0.93)	2.20 (0.54)	
▪ RANGE:	1.97 – 5.47	1.38 – 3.80	

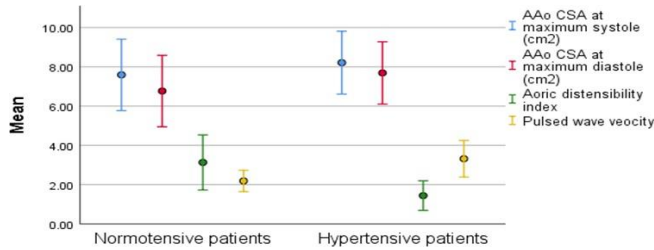


Figure 2. CT aortic measurements among hypertensive and normotensive groups.

The systolic BP level was statistically negatively correlated with ADI (P value = 0.004) and positively correlated with PWV (P value = 0.004), while the diastolic BP level was not statistically significantly correlated with both ADI (P value = 0.052) and PWV (P value = 0.074), Table 3 and Figure 3.

Table 3. Correlation of ADI and PWV with BP level among hypertensive patients

AORTIC DISTENSIBILITY INDEX (ADI)				
	Correlation coefficient (r)	95% CI of the coefficients		P VALUE
		Lower	upper	
SYSTOLIC BP	-0.284	-0.458	-0.091	0.004
DIASTOLIC BP	-0.195	-0.386	0.001	0.052
PULSED WAVE VELOCITY (PWV)				
	Correlation coefficient	95% CI of the coefficients		P VALUE
		Lower	Upper	
SYSTOLIC BP	0.286	0.092	0.457	0.004
DIASTOLIC BP	0.180	-0.004	0.349	0.074

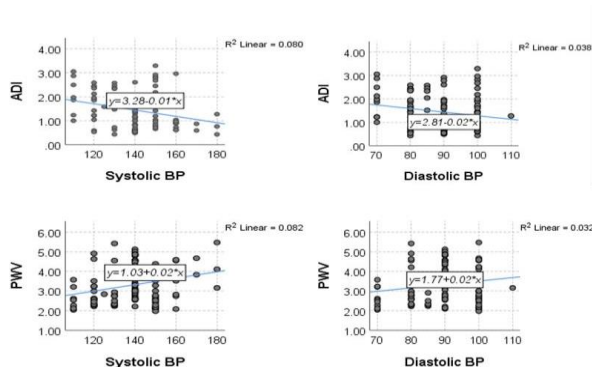


Figure 3. Association of ADI and PWV with BP level among hypertensive patients.

Univariate linear regression analysis revealed ADI was significantly associated with age, hypertension, diabetes, total cholesterol, LDL, HDL, hemoglobin, and serum creatinine, and it was not significantly associated with gender, smoking, and heart rate. However, multivariable analysis revealed ADI was still significantly associated with age and hypertension and became no more significant with others (Table 4).

Table 4. Univariate and multivariable linear regression for association of ADI (outcome variable) with different cardiovascular risk factors (predictor variables) among all patients

Predictor variables	Univariate analysis			Multivariable analysis		
	B	95% CI of the coefficients Lower upper	P value	B	95% CI of the coefficients Lower Upper	P value
AGE (IN YEAR)	-0.083			< 0.001		
GENDER (FEMALE)	0.315-1.121		0.751	0.156		
HYPERTENSION (HYPERTENSIVE)	-1.654-1.964		-1.344	< 0.001-1.201		-1.553 -0.848
DIABETES (DIABETIC)	-0.802-1.228		-0.375	< 0.001-0.150		-0.520 0.219
SMOKING (SMOKERS)	-0.583-1.238		0.063	0.072		
HEART RATE (BEAT/MINUTE)	0.008-0.013		0.029	0.440		
HEMOGLOBIN LEVEL (G/DL)	0.2240.081		0.367	0.002-0.093		-0.222 0.035
S. CREATININE LEVEL (MG/DL)	-2.152-3.186		-1.117	< 0.001		-1.691 0.009
T. CHOLESTEROL LEVEL (MG/DL)	-0.013-0.019		-0.007	< 0.001		-0.008 0.009
LDL LEVEL (MG/DL)	-0.014-0.020		-0.009	< 0.001		-0.012 0.005
HDL LEVEL (MG/DL)	0.033		0.057	0.007		-0.031 0.010

The mean of the total CAC score and the medians of both SIS and SSS were higher in the hypertensive group than in the normotensive one, with statistically significant differences between both groups regarding SIS and SSS (P value < 0.001), and no statistically significant differences between both groups regarding the total CAC score (P value = 0.223), Table 5.

Table 5. Total CAC score, SIS, and SSS among hypertensive and normotensive groups

	HYPERTENSIVE GROUP (100 PATIENTS)	NORMOTENSIVE GROUP (100 PATIENTS)	P VALUE
TOTAL CAC SCORE:	14.59 (40.02)	8.11 (34.70)	0.223
MEAN (SD):	0 - 223	0 - 265	
RANGE:			
SIS:			< 0.001
MEDIAN:	5	0	
RANGE:	0 - 14	0 - 14	
SSS:			< 0.001
MEDIAN:	5	0	
RANGE:	0 - 28	0 - 23	

In the normotensive group, the total CAC score, SIS, and SSS were negatively correlated with ADI (P value = 0.010, P value < 0.001, and P value < 0.001, respectively) and positively correlated with PWV (P value = 0.010, P value < 0.001, and P value < 0.001, respectively). In the hypertensive group, the total CAC score was negatively correlated with ADI (P value = 0.024) and positively correlated with PWV (P value = 0.023), while both SIS and SSS were not correlated with ADI (P value = 0.760 and P value = 0.890, respectively) and with PWV (P value = 0.781, P value = 0.908, respectively), Table 6 and Figure 4.

Table 6. Correlation of total CAC score, SIS, and SSS with both ADI and PWV among hypertensive and normotensive patient groups

	TOTAL CAC SCORE AMONG HYPERTENSIVE PATIENTS				TOTAL CAC SCORE AMONG NORMOTENSIVE PATIENTS			
	Correlation coefficient (r)	95% CI of coefficients		P value	Correlation coefficient (r)	95% CI of coefficients		P VALUE
ADI	-0.226	lower -0.403	upper -0.035	0.024	-0.257	lower -0.463	upper -0.046	0.010
PWV	0.227	0.030	0.403	0.023	0.258	0.018	0.432	0.010
	SIS AMONG HYPERTENSIVE PATIENTS				SIS AMONG NORMOTENSIVE PATIENTS			
	Correlation coefficient (r)	95% CI of coefficients		P value	Correlation coefficient (r)	95% CI of coefficients		P VALUE
ADI	0.031	lower -0.172	upper 0.215	0.760	-0.342	lower -0.519	upper -0.128	< 0.001
PWV	-0.028	-0.214	0.170	0.781	0.342	0.144	0.525	< 0.001
	SSS among hypertensive patients				SSS AMONG NORMOTENSIVE PATIENTS			
	Correlation coefficient (r)	95% CI of coefficients		P value	Correlation coefficient (r)	95% CI of coefficients		P VALUE
ADI	0.014	lower -0.171	upper 0.194	0.890	-0.345	lower -0.511	upper -0.151	< 0.001
PWV	-0.012	-0.218	0.183	0.908	0.345	0.146	0.524	< 0.001

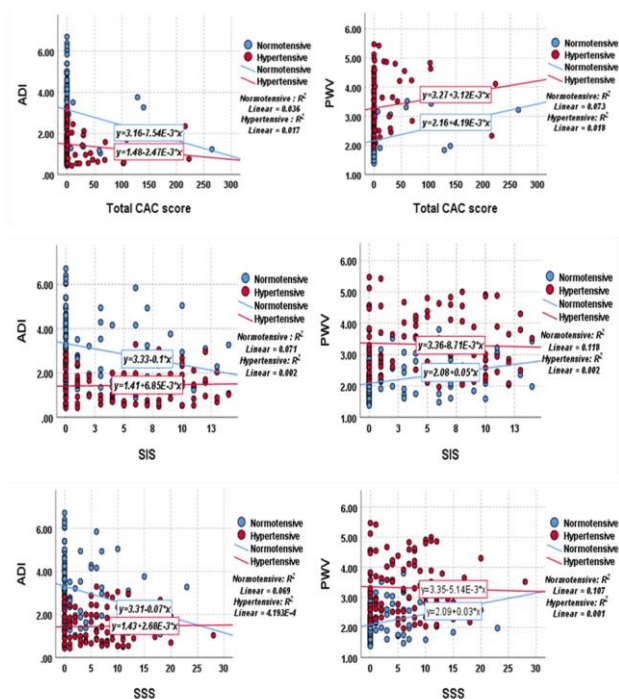


Figure 4. Correlation of total CAC score, SIS, and SSS with both ADI and PWV among hypertensive and normotensive patient groups.

4. Discussion

Research on aortic elasticity has several clinically important applications. Aortic distensibility is connected to the function of aortic bioelasticity and serves as a marker in the pathogenesis of CVD,¹³ and it is the ratio of the aortic deformation under a given pressure level, while aortic stiffness represents the resistance to this deformation.¹⁴ noninvasive imaging techniques using echocardiography, cardiac CT, and magnetic resonance imaging (MRI) have been developed, which can enable quantification of the hemodynamic changes of the aorta and improve diagnosis and risk prediction.¹⁵

Aortic distensibility impairment and stiffness are linked with cardiovascular events, including

hypertension and atherosclerotic CAD, so this highlights their clinical significance. However, the potential mechanisms and clinical applications outline the need for further research to confirm the exact connections of aortic distensibility with cardiovascular risk.¹⁶

The correlation of aortic stiffness with BP level is interesting, as the relationship is bidirectional. Raised BP may induce damage to the arterial wall, leading to accelerated stiffness. Conversely, stiffening of the aorta increases the pulsatility of pressure and affects systolic BP, as it has also been found that elevated carotid artery stiffness was linked with incident hypertension.¹⁷

Aortic distensibility is also linked with atherosclerotic CAD, and the researchers recommend that routine evaluation of aortic stiffness during ECG-gated cardiac CT may be helpful in improving risk stratification approaches and monitoring the progression of CVD.⁴ Additionally, it was noted that aortic stiffness improved the prediction of diagnosis and severity of CAD, and the PWV may be clinically helpful in reducing the number of unnecessary angiographies.⁵

In the current study, aortic distensibility impairment and raised aortic stiffness were closely related to hypertension. Similar to Nabati et al.¹⁸, our study showed that the hypertensive group had a significantly lower ADI and higher PWV in comparison to the normotensive group (P value < 0.001 for both). Also, our study illustrated that elevated systolic BP was correlated with decreased ADI and increased PWV ($r = -0.284$, $r = 0.286$, respectively, P value = 0.004 for both).

Furthermore, the present study demonstrated the conventional cardiovascular risk factors linked with aortic distensibility impairment. Univariable (unadjusted) regression analysis showed that age, hypertension, diabetes mellitus, total cholesterol, LDL, HDL, hemoglobin, and serum creatinine are associated with impairment of aortic distensibility. However, by using

multivariable (adjusted) analysis, only the age and hypertension maintained this association ($B = -0.048$, $B = -1.201$, respectively, P value < 0.001 for both), and this is similar to that reported by Cecelja et al.¹⁹

In agreement with our study, Berge et al.²⁰ reported that the hypertensive group had more advanced atherosclerotic CAD with a higher CAC score and a higher SIS in comparison to the normotensive group. In addition to that, our study calculated SSS, which was also higher among hypertensive patients than normotensive patients (P value < 0.001).

Similar to that illustrated by Ahmadi et al.⁸, our study expressed that total CAC score was negatively correlated with ADI and positively correlated with PWV in both hypertensive ($r = -0.226$ and P value $= 0.024$, $r = 0.227$ and P value $= 0.023$, respectively) and normotensive patients ($r = -0.257$, $r = 0.258$, respectively, P value $= 0.010$ for both). Furthermore, the current study demonstrated that SIS and SSS were inversely correlated with ADI ($r = -0.342$, $r = -0.345$, respectively, P value < 0.001 for both) and directly correlated with PWV ($r = 0.342$, $r = 0.345$, respectively, P value < 0.001 for both) among normotensive patients, while these correlations were not seen among hypertensive patients (P values > 0.05), suggesting they were masked by the presence of atherosclerotic changes induced by hypertension itself.

4. Conclusion

Aortic distensibility impairment and increased aortic stiffness are well associated with hypertension and with the severity of atherosclerotic CAD. Multi-slice CTA provides a good measure for ADI and PWV, which can be useful in predicting hypertension and atherosclerotic CAD.

Disclosure

The authors have no financial interest to declare in relation to the content of this article.

Authorship

All authors have a substantial contribution to the article

Funding

No Funds : Yes

Conflicts of interest

There are no conflicts of interest.

References

1. And Williams B, Mancia G, Spiering W, et al. 2018 ESC/ESH Guidelines for the management of arterial hypertension. *Eur Heart J*. 2019;40(5):475.
2. Jia CF, Jiang YN, Yang ZQ, et al. Ascending Aortic Elasticity and Related Risk Factors Study on Prehypertension Patients. *Am J Hypertens*. 2017;30(1):61-66.
3. Stoiber L, Mahfoud F, Zamani SM, et al. Renal sympathetic denervation restores aortic distensibility in patients with resistant hypertension: data from a multicenter trial. *Clin Res Cardiol*. 2018;107(8):642-652.
4. Oberoi S, Schoepf UJ, Meyer M, et al. Progression of arterial stiffness and coronary atherosclerosis: longitudinal evaluation by cardiac CT. *AJR Am J Roentgenol*. 2013;200(4):798-804.
5. Yannoutsos A, Ahouah M, Dreyfuss Tubiana C, Topouchian J, Safar ME, Blacher J. Aortic stiffness improves the prediction of both diagnosis and severity of coronary artery disease. *Hypertens Res*. 2018;41(2):118-125.
6. Stergiou GS, Palatini P, Parati G, et al. 2021 European Society of Hypertension practice guidelines for office and out-of-office blood pressure measurement. *J Hypertens*. 2021;39(7):1293-1302.
7. Abbara S, Blanke P, Maroules CD, et al. SCCT guidelines for the performance and acquisition of coronary computed tomographic angiography: A report of the society of Cardiovascular Computed Tomography Guidelines Committee: Endorsed by the North American Society for Cardiovascular Imaging (NASCI). *J Cardiovasc Comput Tomogr*. 2016;10(6):435-449.
8. Ahmadi N, Nabavi V, Hajsadeghi F, et al. Impaired aortic distensibility measured by computed tomography is associated with the severity of coronary artery disease. *Int J Cardiovasc Imaging*. 2011;27(3):459-469.
9. Ganten M, Boese JM, Leitermann D, Semmler W. Quantification of aortic elasticity: development and experimental validation of a method using computed tomography. *Eur Radiol*. 2005;15(12):2506-2512.
10. Bramwell JC, Hill AV. The velocity of pulse wave in man. *Proceedings of the Royal Society of London. Series B, Containing Papers of a Biological Character*. 1922;93(652):298-306.
11. Cundari G, Marchitelli L, Pambianchi G, et al. Imaging biomarkers in cardiac CT: moving beyond simple coronary anatomical assessment. *Radiol Med*. 2024;129(3):380-400.
12. Min JK, Shaw LJ, Devereux RB, et al. Prognostic value of multidetector coronary computed tomographic angiography for prediction of all-cause mortality. *J Am Coll Cardiol*. 2007;50(12):1161-1170.
13. Shehata M, Elsayegh A, Gomaa Y, Gamal M. Using aortic distensibility index to detect coronary stenosis. *Acta Cardiol*. 2015;70(4):465-472.
14. Sethi S, Rivera O, Oliveros R, Chilton R. Aortic stiffness: pathophysiology, clinical implications, and approach to treatment. *Integr Blood Press Control*. 2014;7:29-34.
15. Whitlock MC, Hundley WG. Noninvasive Imaging of Flow and Vascular Function in Disease of the Aorta. *JACC Cardiovasc Imaging*. 2015;8(9):1094-1106.
16. Mileva N, Velikova T, Velikov T, Vassilev D. Aortic Elasticity and Cardiovascular Risk Stratification: A Narrative Review on the Current Understanding. *Journal of Vascular Diseases*. 2024;3(1):88-101.
17. Youssef G, El Tebi I, Osama D, et al. Familial history of hypertension as a predictor of increased arterial stiffness in normotensive offspring. *Egypt Heart J*. 2017;69(1):37-44.
18. Nabati M, Namazi SS, Yazdani J, Sharif Nia H. Relation Between Aortic Stiffness Index and Distensibility with Age in Hypertensive Patients. *Int J Gen Med*. 2020;13:297-303.
19. Cecelja M, Ruijsink B, Puyol-Antón E, et al. Aortic Distensibility Measured by Automated Analysis of Magnetic Resonance Imaging Predicts Adverse Cardiovascular Events in UK Biobank. *J Am Heart Assoc*. 2022;11(23):e026361.
20. Berge CA, Eskerud I, Almeland EB, et al. Relationship between hypertension and non-obstructive coronary artery disease in chronic coronary syndrome (the NORIC registry). *PLoS One*. 2022;17(1):e0262290.