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Impaired Aortic Elasticity and Diastolic Functions Are Associated with Findings of Coronary Computed Tomographic Angiography

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
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Background: Coronary artery disease (CAD) is the leading cause of mortality and morbidity worldwide. Aortic elasticity and diastolic functions are helpful parameters in assessment of CAD. In this study we aimed to learn whether diastolic function and aortic elastic properties measured by echocardiography are associated with coronary calcium score (CACS), epicardial fat volume (EFV), and plaque area measured by coronary tomographic angiography.

Material/Methods: We enrolled 106 consecutive patients suspected of CAD undergoing coronary CTA and transthoracic echocardiography in this prospective study. Total CACS, plaque area, and EFV were calculated via CTA. Aortic stiffness index (ASI) and aortic distensibility (AD) were measured via echocardiography.

Results: The patients with diastolic dysfunctions of any degree had significantly higher ASI, higher CACS, higher plaque area, and EFV. We found that as the ASI increases, the CACS and total coronary plaque area both increase, showing that there is a strong positive correlation between ASI, CACS, and total coronary plaque area. There was a significant correlation between ASI and EFV, but with a lower statistical value.

Conclusions: Aortic elasticity was correlated with CACS and plaque area. Diastolic dysfunction was observed more commonly among patients with higher CACS and EFV. Epicardial fat volume was not as strong as CACS in reflecting aortic elasticity.

MeSH Keywords: Epicardial Mapping • Multidetector Computed Tomography • Vascular Stiffness

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Background

Coronary artery disease (CAD) is the leading cause of mortality and morbidity worldwide and thus, its prompt diagnosis is a major healthcare goal. In this respect, coronary computed tomographic angiography (CTA) has evolved as an emerging diagnostic modality. It has been widely used for diagnosis and follow-up of CAD, in emergency assessment of acute chest pain, and in evaluation of graft patency in coronary bypass surgery patients [1]. In addition to degree of coronary vessel obstruction, it informs about coronary calcium score, epicardial fat, and coronary plaque volume [1,2], which are all parameters documented to be correlated with asymptomatic atherosclerosis because they are total effects of all cardiovascular risk factors on the heart and coronary arteries [2–4]. It is especially valuable in case of positive (or outward) remodelling in which conventional coronary angiography may demonstrate normal coronary luminal structure [5]. Diagnosing asymptomatic individuals, the subgroup at greater risk for developing cardiovascular events, is fundamental in any strategy aimed to reduce adverse cardiovascular events [6]. Thus, the parameters obtained from CTA are very useful in risk stratification and in deciding on intensity of treatment among asymptomatic individuals.

Another noninvasive approach for early detection of subclinical atherosclerosis is evaluation of arterial structure and function. In this respect, measurements of arterial elasticity, intima-media thickness, and endothelial functions are clinically useful for this purpose [7,8]. Arterial elasticity is mostly expressed as aortic distensibility (AD) and aortic stiffness index (ASI) and can be measured via pulse wave velocity (PWV) or echocardiography [7,8].

Left ventricular diastolic functions reflect left ventricular filling pressures. High blood pressure and coronary ischemia result in diastolic dysfunction of varying degrees. Undetected disease and insufficient treatment can lead to heart failure with preserved ejection fraction [9]. Thus, any related diastolic dysfunction needs prompt management.

Showing the relation between diastolic functions, aortic elasticity, and parameters related to coronary computed tomographic angiography will allow clinicians to use these parameters interchangeably in detection of subclinical atherosclerosis. The literature is lacking in data about the relation between echocardiographically measured aortic elastic properties and CTA-related parameters. In this study we aimed to determine whether diastolic function and aortic elastic properties measured by echocardiography are associated with coronary calcium score, epicardial fat volume, and plaque volume measured by coronary tomographic angiography.

Material and Methods

Subjects

A total of 106 consecutive patients suspected of CAD undergoing coronary CTA and transthoracic echocardiography were enrolled in this prospective study. Subjects 30 to 65 years old were included in the study. We excluded patients with previously diagnosed coronary artery disease, chronic kidney disease (creatinine >1.4 mg/dl), advanced liver disease, stroke, cancer, infection, hyper- or hypothyroidism, symptomatic congestive heart failure, left ventricle ejection fraction less than 50%, and any congenital heart disease. Each subject provided informed consent and our study was approved by our institutional ethics committee.

The following data were also obtained: age, sex, height, weight, cardiovascular risk factors (hypertension, diabetes mellitus, hypercholesterolemia, family history of premature CAD, and smoking), heart rate during scanning, and laboratory findings such as serum levels of high-density lipoprotein (HDL), low-density lipoprotein (LDL), total cholesterol, triglyceride (TG), creatinine, thyroid stimulating hormone (TSH), and fasting blood glucose were also measured for all patients. Body mass index (BMI) was defined according to the World Health Organization criteria. Patients were classified as normal weight (BMI 18.5–24.9 kg/m^2), overweight (BMI 25.0–29.9 kg/m^2), obese class I (BMI 30.0–34.9 kg/m^2), obese class II (BMI 35.0–39.9 kg/m^2), or obese class III (BMI 40 kg/m^2 or more).

CT protocol

Patients underwent clinically indicated CTA performed with 64-row multidetector CT (Philips Medical System, Brilliance 64, Best, Netherlands). Non-contrast images were obtained for coronary calcium scoring.

Scanning parameters for the unenhanced calcium scoring scan were: 100 kV tube voltage, tube current was adjusted according to the body mass index (BMI), 0.28-s rotation time, and 2.5-mm slice thickness. Quantification of coronary artery calcium was performed using software for calcium scoring. All regions with a density over 130 Hounsfield units were considered as potential calcifications. We employed quantitative coronary calcium scoring using the methods previously described by Agatston et al. [10]. Total coronary calcium score was determined by summing individual lesion scores from each of the 4 main coronary arteries: left main coronary (LM), left anterior descending coronary (LAD), left circumflex coronary (LCX), and right coronary arteries (RCA) [10].

Then, routine CTA imaging was performed: a single-dose oral β-blocker (metoprolol) was given 1 hour before the examination

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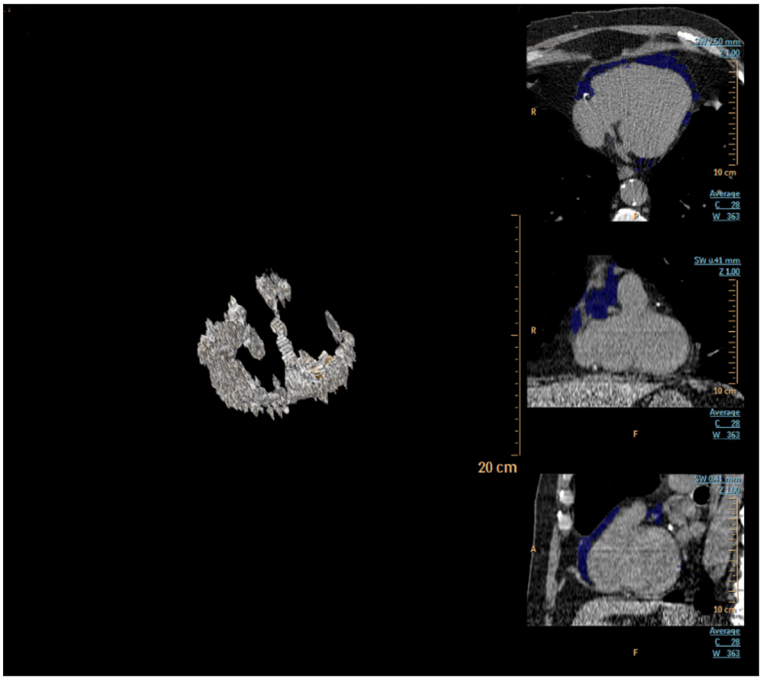

Figure 1. Evaluation of epicardial fat volume using a multiplanar reformat and volume-rendering techniques (VRTs).

to all patients with a heart rate above 70 beats/min if there were no contraindications. Lopromide (70 ml, Ultravist 370, 370 mg/mL, Bayer Schering Pharma, Berlin, Germany) followed by 60 ml of saline was injected at a flow rate of 5 ml/s into the antecubital vein. A bolus tracking technique was used and the region of interest was located in the left ventricle. The retrospective low-pitch electrocardiogram (ECG)-gated spiral scan mode with ECG-pulsing was used, depending on the heart rate. The scanning protocols were carried out as follows: tube voltage, 100 kV or 120 kV for severely obese patients (BMI>30); gantry rotation time, 270 ms; slice acquisition, 2×128×0.625 mm by means of z-flying focal spot; pitch, 0.23; and tube current, 370 mAs or 320 mAs. MDCT data sets were reconstructed in the best systolic and best diastolic phases of the R-R interval, with a slice thickness of 0.75 mm and 0.4 mm increments.

CT imaging analysis

All images were evaluated for volumetric analysis at the work station (Extended Brilliance, Version 3.5.0.2254; Philips Medical System) using multi-planar reformat and volume-rendering techniques (VRTs). Coronary calcium score, epicardial fat volume, and coronary plaque volume were independently determined by 2 radiologists and were averaged. Epicardial fat, defined as the adipose tissue within the visceral layer of the pericardium, was measured at each axial noncontrast CT slice by manually tracing the pericardium; the total epicardial fat volume was then calculated by slice summation of the single-slice data (Figure 1).

We did not investigate the impact of the coronary artery stenosis on the clinical outcome, as this was not an objective of this study.

Echocardiography protocol

Two-dimensional, M-mode, pulsed Doppler, and tissue Doppler echocardiography were performed on an ultrasound machine (Presoundalpha 7, IPF 1701 Model, 2009; Hitachi Aloka Medical, Ltd. Tokyo, Japan) with a 2.5-MHz transducer before performing CTA by a cardiologist blinded to the study. Standard 2-dimensional measurements (LV diastolic and systolic dimension, ventricular septum and posterior wall thickness, left atrial diameter, and LV ejection fraction) were obtained as recommended by the American Society of Echocardiography [11]. The mitral inflow velocities were traced and peak velocity of early diastolic mitral inflow (E) and late diastolic mitral inflow (A) were obtained. Mitral annular velocities were obtained by Doppler tissue imaging using the pulsed-wave mode. The filter was set to exclude high-frequency signals, and the Nyquist limit was adjusted to a range of 15 to 20 cm/s. Gain and sample volume were reduced as possible to allow a clear tissue signal with minimal background noise. Early diastolic mitral annular (Em), late diastolic (Am), and systolic velocities (Sm) of the mitral annulus were measured from the apical 4-chamber view with a 2- to 5-mm sample volume placed at the lateral edge of the mitral annulus. All measurements were carried out at expirium. Normal diastolic function (DD) was defined as E/A ratio >1, Em >8 cm/s, Em/Am >1 and E/Em <8. Grade I DD was defined E/A ratio <1, Em <8 cm/s, Em/Am <1, and E/Em <8; Grade II DD was defined E/A ratio >1 and <2, Em <8 cm/s, Em/Am <1 and E/Em between 8 and 15; and Grade III DD was defined E/A ratio >2, Em <8 cm/s and E/Em >15.

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Table 1. Demographic characteristics of the patients.

Mean Age (year)	50±9
Gender (female/male)(%)	40/66 (38/62)
BMI (kg/m^2)	28.5±4.1
BMI clusters	
Normal (%)	21 (20)
Overweight (%)	51 (48)
Obese class I (%)	24 (23)
Obese class II (%)	10 (9)
Presence of DM (yes/no) (%)	12/94 (11/89)
Presence of hypertension (yes/no) (%)	35/71 (33/67)
Cigarette smoking (yes/no) (%)	26/80 (25/75)
Family history of CAD (yes/no) (%)	10/96 (9/91)

BMI – Body Mass Index; DM – diabetes mellitus; CAD – coronary artery disease.

The blood pressure (BP) levels were measured from the right and left arms of the subjects in a sitting position by 1 trained observer blind to the study in the echocardiography laboratory. BP was measured twice with 5-minute interval. The systolic BP (SBP) and diastolic BP (DBP) were recorded at the first and fifth Korotkoff phases, respectively, using a mercury sphygmomanometer. The average of the 4 BP measurements was used for analysis. The difference of SBP and DBP was used as pulse pressure (PP).

Following the echocardiographic examination of heart, at parasternal long axis M-mode images, the systolic (Asd) and diastolic (Add) aortic diameters of ascending aorta from lower margin of upper wall to upper margin of lower wall were measured 3 cm distal to the aortic valve level, discriminating diastole and systole by using simultaneous ECG recordings. Aortic stiffness index is calculated by using ASI=ln (SBP/DBP)/[(Asd-Add)/Add] formula and aortic distensibility is obtained by using AD[1/(10^3×mmHg)]=2×[(Asd-Add)/Add]/PP formula [12].

Statistical analysis

Statistical analyses were performed using the SPSS software version 18. Continuous variables are presented as mean±SD and categorical variables are presented as frequencies (%)., Creatinine, total cholesterol, LDL, and all other continuous variables except for hemoglobin did not have normal distribution according to the Kolmogorov-Smirnov test. Categorical variables were compared using the chi-square test. Spearman simple correlation analyses were performed to determine the association between CTA findings and echocardiographic and laboratory parameters. The Mann-Whitney U test and Kruskal-Wallis test were used to compare categorized groups, as appropriate. A p value of less than 0.05 was considered to show a statistically significant result.

Table 2. Laboratory findings of the patients.

	Values (n=106)
Hemoglobin (gr/dl)	14.2±1.4
FBG (gr/dl)	98±13
Creatinin (mg/dl)	0.89±0.13
Total cholesterol (mg/dl)	194±40
Triglyceride (mg/dl)	173±75
HDL (mg/dl)	42±10
LDL (mg/dl)	118±32
TSH (mIU/L)	1.54±0.71

FGB – fasting blood glucose; HDL – high density lipoprotein; LDL – low density lipoprotein; TSH – thyroid stimulating hormone.

Results

We studied 106 patients (40 females and 66 males) with a mean age of 50±9 years; 11% of the patients (n=12) were diabetic and 33% (n=35) had the diagnosis of hypertension (Table 1); 20% of all patients had normal BMI and the rest were overweight or obese. Laboratory findings of the patients are given in Table 2.

The study population was composed of patients with relatively preserved left ventricle ejection fraction of 62±3% and approximately half of the study population (n=55) had normal diastolic functions (Table 3). The patients with diastolic dysfunctions of any degree had significantly higher ASI (p=0.000 Z score –6.694), higher CACS (p=0.000 Z score –5.880), higher plaque area (p=0.000 Z score –5.908), and EFV (p=0.000 Z score –4.850), but they had similar total cholesterol, triglyceride, LDL and HDL levels compared to patients with normal diastolic function.

Average systolic blood pressure at time of echocardiography examination was 121±15 mmHg. Only 9% of patients (n=10) had SBP 140 mmHg and above. As expected, those with SBP of 140 mmHg and above had significantly worse diastolic dysfunction measured by Em/Am (p=0.001 Z score –3.353), and they had higher ASI (3.96±0.25) compared to those with SBP less than 140 mmHg (2.86±0.60, p=0.000 Z score –4.454). They had significantly higher CACS (p=0.000 Z score –4.110) and plaque area (p=0.000 Z score –4.061) but there was no significant difference in EFV (p=0.158 Z score –1.411).

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Table 3. Echocardiographic, tomographic and hemodynamic measurements.

	Values (total n=106)
SBP (mmHg)	121±15
DBP (mmHg)	78±5
Aort diameter in systole (mm)	32±4
Aort diameter in diastole (mm)	29±5
LVEF (%)	62±3
LA diameter (mm)	38±4
Mitral E/A ratio	1.3±0.4
TDI Em/Am ratio	1.2±0.6
Diastolic function grade (n=56)	
Normal (%)	55 (52)
Grade I (%)	39 (37)
Grade II (%)	10 (9)
Grade III (%)	2 (2)
Aortic Stiffness Index	2.96±0.66
Aortic distensibility [1/(10^3×mmHg)]	4.87±3.05
Total coronary artery calcium score	83±181
Total CAC score (n=49)	
0	63 (59)
1–100 (%)	23 (22)
101–400 (%)	9 (9)
401 and above (%)	11 (10)
Total coronary artery plaque area (mm^2)	30±62
Epicardial fat tissue volume (cm^3)	38±31

SBP – systolic blood pressure; DBP – diastolic blood pressure; LVEF – left ventricle ejection fraction; TDI – tissue Doppler imaging; CAC – coronary artery calcium.

Aortic elasticity expressed as ASI and AD was well correlated to CACS, plaque area, and EFV. It is known that ASI and AD are inversely correlated parameters. We found that higher ASI was associated with higher total CACS (p=0.000, rho value 0.769) and total coronary plaque area (p=0.000, rho value 0.764). A similar but inverse relation was shown between AD and CACS or plaque area (Table 4). A weaker significant correlation was found between ASI and EFV (p=0.007 rho value 0.259). Total CACS 1–100 indicates subclinical atherosclerosis (SA). In this study, 59% of all patients (n=63) had zero CACS and 22% (n=23) had CACS 1–100. Patients with SA had significantly more impaired aortic elasticity compared to zero CACS patients, meaning higher ASI and lower AD values among patients with SA. This group also had higher frequency of diastolic dysfunction with grade I or more (70% *vs.* 25%, p=0.000). Except for HDL, which was significantly lower in the SA group (37±6 *vs.* 45±11 mg/dl; p=0.003 Z score –3.012), all other laboratory findings and BMIs were statistically similar between these 2 groups of patients. Average age of the group with SA was significantly older (56±6 years *vs.* 45±8 p=0.000 Z score –5.063) and number of patients with the diagnosis of hypertension was also statistically higher among SA patients (48% *vs.* 16% p=0.002) but numbers of diabetics, smokers and family history of premature CAD were statistically similar between the 2 groups.

To exclude the effect of age and hypertension on diastolic function and aortic elasticity, patients ages 40–55 years were reanalyzed. In this case, patients with zero CAC (CAD negative group)(n=36) had statistically similar age and BMI values and similar cardiovascular risk factors frequencies (DM, HT, family history of premature CAD, smoking) compared to patients with CACS 1 or more (CAD group) (n=12). In the analysis, we found that all laboratory findings were statistically similar for the groups, but aortic elasticity was significantly more impaired in the CAD-positive group than in the CAD-negative group (Table 5). We did not find any statistically significant relation between the groups in epicardial fat tissue volume.

Discussion

Aortic stiffness is one of the most important predictors of future cardiovascular adverse events [13]. PWV has been the method used most frequently to measure aortic stiffness and echocardiography and computed tomography have been rarely used [13,14]. Coronary computed tomographic angiography (CTA) has evolved as an emerging diagnostic modality and is increasingly used in medical practice. Parameters derived from CTA (e.g., coronary calcium score, plaque area, and epicardial fat) have been studied and used for cardiovascular risk stratification [15]. Although the relation of calcium score with aortic stiffness has been known, knowledge about the relation between stiffness and epicardial fat volume (EFV) is limited. In this study, we measured aortic elasticity via echocardiography and detected subclinical atherosclerosis via CTA, and we compared CTA-derived EFV, total coronary calcium score, and plaque area to echocardiographically measured aortic stiffness index and aortic distensibility.

Arterial stiffness of various parts of the vasculature (e.g., carotid, brachial, and femoral arteries) have been used to detect early atherosclerosis [16,17], but there are some limiting aspects of these methods. For example, arterial stiffness measured by carotid-femoral PWV revealed an insignificant relation to cardiovascular risk factors except for age and blood pressure [18]. A high level of experience and exposure of the inguinal region are necessary for the measurement and its applicability

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Table 4. Correlation analysis of the parameters.

	Total coronary artery calcium score	Total coronary artery plaque area (mm^2)	Epicardial fat tissue volume (cm^3)
Age (year)	p value 0.000	p value 0.000	p value 0.000
	rho value 0.666	rho value 0.675	rho value 0.381
BMI (kg/m^2)	p value 0.026	p value 0.025	p value 0.000
	rho value 0.217	rho value 0.217	rho value 0.394
SBP (mmHg)	p value 0.000	p value 0.000	p value 0.091
	rho value 0.662	rho value 0.664	rho value 0.165
DBP (mmHg)	p value 0.000	p value 0.000	p value 0.062
	rho value 0.367	rho value 0.374	rho value 0.182
TDI Em/Am ratio	p value 0.000	p value 0.000	p value 0.000
	rho value –0.616	rho value –0.620	rho value –0.404
Aortic Stiffness Index	p value 0.000	p value 0.000	p value 0.007
	rho value 0.769	rho value 0.764	rho value 0.259
Aortic sistensibility [$1/(10^3 \times mmHg)$]	p value 0.000	p value 0.000	p value 0.014
	rho value –0.777	rho value –0.772	rho value –0.237

BMI – Body Mass Index; SBP – systolic blood pressure; DBP – diastolic blood pressure; TDI – tissue Doppler imaging.

is limited. Furthermore, methods involving muscular vessels such as femoral or brachial arteries measure not only elastic arterial stiffening but also muscular stiffening, which has different implications [19]. Here, we used the aorta to measure arterial stiffening via echocardiography, which better reflects central arterial stiffness and is easy to apply.

Diastolic functions of the heart reflect left ventricle filling pressure involving relaxation and/or filling and/or distensibility of the myocardium. Myocardial hypertrophy, ischemia, and age are the most common causes of DD. Diastolic functions are impaired among patients with hypertension, diabetes, and coronary artery disease [20]. We found that patients with DD had more impaired aortic elasticity, higher CACS, more total plaque area, and higher EFV. To remove the effect of age and hypertension on diastolic functions, we carried out subgroup analysis of patients without hypertension and with ages 40–55 years (n=38); we still observed significantly higher ASI (p=0.045, z score –2.007), higher CACS (p=0.016, z score –2.411), more total plaque area (p=0.009, z score –2.612) and higher EFV (p=0.015, z score –2.435) among patients with DD (n=8) compared to patients without DD (n=30). All these results show that DD was influenced by factors far beyond age and blood pressure effects and needs further research.

Because the feasibility of the 4-detector row CTA was introduced, the diagnostic accuracy of CTA has improved as the technology has evolved [1]. Sensitivities and specificities of 64-detector row CTA are 85–95% [21], but there are conflicting data regarding the clinical interpretation and application of CACS with low likelihood for CAD. To increase the value of CACS, other CTA-derived parameters such as total plaque area and EFV may be beneficial. In our study, we found that CACS was significantly correlated with total coronary plaque area (p=0.000 rho=0.997) but not with EFV (p=0.085, rho=0.168). It is known that body mass index affects EFV [22]. Subgroup analysis was carried out for non-obese patients to remove the effect of obesity on EFV (n=72). In this reanalysis, CACS was found to be well correlated with EFV (p=0.019, rho=0.277), and subgroup with CACS 1 or more (n=25) also had significantly higher EFV (43±29 cm^3) than patients with zero CACS (n=47, 29±30 cm^3) (p=0.009 Z score=–2.620). However, further studies are needed to explain the relation between EFV and CACS.

Aortic stiffness is a well known marker for atherosclerosis [14,19]. Its relation with CTA-derived parameters has been studied but there is limited data about echocardiographically-measured aortic elasticity and CTA-derived parameters. Here, we used ASI and AD measured via echocardiography instead of the PWV method. The echocardiographic method is easy to apply and measures central arterial stiffness instead of peripheral stiffness [13]. Here, we found CACS was significantly correlated to ASI (p=0.000, rho value 0.769) and AD (p=0.000, rho value –0.777). A similar significant relation was

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Table 5. Subgroups analysis of patients with ages between 40 to 55 years.

	Patients with CAD (n=36)	Patients without CAD (n=12)	p value z score
Age (year)	49±3	47±4	0.083 –1.732
BMI (kg/m²)	27.1±3.8	28.8±4.6	0.294 –1.049
SBP (mmHg)	130±25	118±8	0.67 –1.833
DBP (mmHg)	79±8	77±4	0.117 –1.568
TDI Em/Am ratio	1.42±0.71	1.50±0.54	0.535 –0.621
Aortic Stiffness Index	3.04±0.61	2.56±0.29	0.003 –2.954
Aortic distensibility 1/(10^3×mmHg)]	4.05±2.65	6.21±2.06	0.004 –2.860
Epicardial fat tissue volume (cm^3)	46±43	31±22	0.505 –0.667

BMI – Body Mass Index; SBP – systolic blood pressure; DBP – diastolic blood pressure; TDI – tissue Doppler imaging.

found between coronary plaque area and ASI or AD. The relation between EFV and ASI was weaker but still significant (p=0.007, rho value 0.259).

EFV reflects visceral adiposity rather than general fat content [22]. Epicardial fat thickness and volume have been strongly correlated to obesity, impaired fasting glucose, insulin resistance, metabolic syndrome, hypertension, diabetes mellitus, and atherosclerosis [23–25], but there are controversies related to epicardial adipose tissue. There are studies implicating the cardioprotective effect of epicardial adipose tissue through local secretion of anti-inflammatory and anti-atherogenicadipokines such as adiponectin and adrenomedullin. Iacobellis et al. demonstrated that CAD downregulated these adipokines [26]. There are conflicting data about sex difference in epicardial adiposity [26,27]. While Smith et al. reported that age was not related to epicardial fat tissue in their autopsy study, the Framingham offspring cohort study revealed a significant correlation between age and epicardial fat [27,28]. Considering all these data, to exclude the age and obesity effects on EFV, we carried out subgroups analysis of patients ages 40–55 years.

We did not find any correlation between EFV and ASI (p=0.897, rho=–0.019) but we did find a strong relation between CACS and ASI (p=0.000, rho=0.497). In this subgroup analysis also we found that patients with CAD (CACS 1 or more) had significantly higher ASI than patients without CAD (3.04±0.61 *vs.* 2.56±0.29 accordingly, p=0.003, Z score=–2.954), but the 2 groups did not differ in age, laboratory findings, BMI, SBP, DBP, or EFV. All these results indicate that CACS, but not EFV, was strongly related to aortic elasticity.

Conclusions

Aortic elasticity was strongly correlated to CACS and plaque area. Diastolic dysfunction was observed more commonly among patients with higher CACS and EFV. Epicardial fat volume was not as strong as CACS in reflecting aortic elasticity.

Conflict of interest

We have declared that there is no conflict of interest.

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