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Evaluation of Aortic Elasticity Parameters Measured by Transthoracic Echocardiography in a Normotensive Population: A Single-Center Study

Normotansif Bir Popülasyonda Aortik Elastikiyet Parametrelerinin Transtorasik Ekokardiyografi ile Değerlendirilmesi: Tek Merkezli Bir Çalışma

ABSTRACT

Objective: Impaired arterial elastic features is one of the earliest manifestations of atherosclerosis in the vessel wall and is associated with the development of cardiovascular disease and increased mortality and morbidity. In this study, we aimed to investigate the mean values of aortic elasticity parameters in a normotensive population with transthoracic echocardiography and to evaluate these values in different age groups and their relationship with other risk factors.

Methods: This retrospective study included 405 subjects who met the inclusion criteria among 2880 individuals screened between 2020 and 2022. The study population was divided into 5 groups according to their age. Aortic elasticity parameters (aortic strain, aortic stiffness index, and aortic distensibility) were calculated from the associated formulas by measurements made from the ascending aorta in the parasternal long axis.

Results: In 405 subjects (mean age 42.18 ± 10.39, 54.3% female), the mean aortic strain value was 15.14 ± 3.56%, the mean aortic stiffness index was 3.24 ± 1.05, and the mean aortic distensibility was 7.48 ± 2.36 $cm^2/dyn^1/10^3$. It was observed that aortic strain and distensibility values significantly decreased with increasing age groups, while aortic stiffness significantly increased. All 3 aortic elasticity parameters were strongly correlated to age. In the multivariate linear regression analysis, age was found to be an independent factor for all aortic elasticity parameters.

Conclusion: Aortic elasticity parameters can be evaluated with transthoracic echocardiography in daily practice. Comparing these measurements with normal values in similar age groups may help to detect patients with increased cardiovascular risk in the early period, regardless of the other risk factors.

Keywords: Aortic stiffness, aortic elasticity, aortic strain, atherosclerosis, cardiovascular risk factors

ÖZET

Amaç: Bozulmuş arteriyel elastik özellikler, damar duvarındaki aterosklerozun en erken belirtilerinden birisidir ve kardiyovasküler hastalık (KV) gelişimi, artmış mortalite ve morbidite ile ilişkilidir. Bu çalışmada, transtorasik ekokardiyografi (TTE) ile normotansif bir popülasyonda aort elastikiyet parametrelerinin ortalama değerlerini farklı yaş gruplarında araştırmayı ve diğer risk faktörleri ile ilişkisini değerlendirmeyi amaçladık.

Yöntem: Bu retrospektif çalışmaya, 2020-2022 yılları arasında merkezimizde taranan 2880 kişi arasından, dahil edilme kriterlerini karşılayan 405 kişi dahil edildi. Çalışma popülasyonu yaşlarına göre beş gruba ayrıldı. Aortik elastikiyet parametreleri (aortik strain, aort sertliği indeksi ve aort gerilebilirliği), parasternal uzun eksende, çıkan aortadan yapılan ölçümlerle, ilgili formüllerden hesaplandı.

Bulgular: Çalışmaya alınan 405 kişinin (ortalama yaş 42,18 ± 10,39, %54,3 kadın) ortalama aortik strain değeri %15,14 ± 3,56, ortalama aort sertliği indeksi 3,24 ± 1,05 ve ortalama aort gerilebilirliği 7,48 ± 2,36 cm^2 dyn^{-1} 10^{-3} olarak saptandı. Artan yaş grupları ile aortic strain ve gerilebilirlik değerlerinin anlamlı olarak azaldığı, aort sertliğinin ise anlamlı olarak arttığı gözlendi. Her üç aortik elastikiyet parametresi de yaşla güçlü bir şekilde ilişkiliydi. Çok değişkenli doğrusal regresyon analizinde, yaşın tüm aortik elastikiyet parametreleri için bağımsız bir faktör olduğu bulundu.

ORIGINAL ARTICLE
KLİNİK ÇALIŞMA

Betül Cengiz Elçioğlu[1]
Alparslan Kılıç[1]
Onur Baydar[1]
Şükrü Taylan Şahin[2]
Hülya Gamze Çelik[2]
Vedat Aytekin[1]
Saide Aytekin[1]

[1]*Department of Cardiology, Koç University Hospital, İstanbul, Türkiye*
[2]*Department of Cardiology, American Hospital, İstanbul, Türkiye*

Corresponding author:
Saide Aytekin
✉ saideaytekin@gmail.com

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Sonuç: Günlük pratikte TTE ile aortik esneklik parametreleri değerlendirilebilir. Bu ölçümlerin benzer yaş gruplarındaki normal değerlerle karşılaştırılması, diğer risk faktörlerinden bağımsız olarak artmış KV riski olan hastaların erken dönemde saptanmasına yardımcı olabilir.

Anahtar Kelimeler: Aort sertliği, aortik elastikiyet, aortik strain, ateroskleroz, kardiyovasküler risk faktörleri

Atherosclerosis is a chronic, systemic inflammatory disease that develops in the wall of medium and large arteries and is the main underlying cause of cardiovascular diseases (CVDs).[1] Early detection of the atherosclerosis process is important in the prevention of CVD. Arterial elasticity is determined by the amount of elastin and collagen content in the vessel wall. Disruption of this balance in favor of excess collagen results in increased arterial stiffness, which is one of the earliest indicators of the structural changes in the vessel wall causing atherosclerosis.[2-4] Cardiovascular risk factors, such as hypertension (HT), diabetes mellitus (DM), especially aging, are closely associated with arterial stiffness.[5]

Previous studies have revealed the association of the arterial stiffness with the development of CVD and CV events.[6,7] Various mechanisms have been proposed to explain this relationship. Increased arterial stiffness raises systolic blood pressure, resulting in an increase in myocardial oxygen demand. Also, decreased diastolic pressure impairs coronary perfusion and increased pulse pressure leads to arterial remodeling.[8-10] All these factors support the importance of evaluating aortic elasticity in clinical practice.

Various methods are available for the evaluation of arterial stiffness. While measurements of carotid-femoral and brachial-ankle pulse wave velocity (PWV) are commonly used non-invasive methods, there are also studies evaluating aortic stiffness with 2-dimensional speckle tracking echocardiography (2D-STE).[11-13] Arterial stiffness can be also assessed by calculating aortic elasticity parameters with transthoracic echocardiography (TTE). It is an easy-to-apply and time-efficient method that does not require any other equipment or software.[14,15]

Although there are comparison and follow-up studies in different patient groups of aortic stiffness measured with TTE,[16-18] there is no study investigating normal values in normotensive individuals without overt CVD. We aimed in this study to investigate the mean values of aortic elasticity parameters with TTE in a normotensive population and to evaluate these values in different age groups and their relationship with other risk factors.

ABBREVIATIONS

2D-STE	2-dimensional speckle tracking echocardiography
AoD	Aortic diameter
CVDs	Cardiovascular diseases
DBP	Diastolic blood pressures
DM	Diabetes mellitus
ECG	Electrocardiogram
HT	Hypertension
LV	Left ventricular
LVEF	LV ejection fraction
PWV	Pulse wave velocity
SBP	Systolic blood pressure
TTE	Transthoracic echocardiography

Material and Methods

Study Group

This is a retrospective study in which 405 subjects were included after screening 2880 individuals who applied to cardiology outpatient clinics of our institute between 2020 and 2022 within the scope of the check-up program. Patients with known CVD, chronic systemic disease, hypertension (HT), diabetes mellitus (DM), connective tissue disorders, congenital aorta and aortic valve disease, more than mild valvular heart disease, left ventricular (LV) wall motion abnormalities, LV ejection fraction (LVEF) <55%, other than sinus rhythm, and conduction abnormalities on electrocardiogram (ECG) were excluded from the study. Significant coronary artery disease was ruled out by treadmill exercise tests in 301 subjects (74.3%) and by coronary computed tomography angiography in 28 subjects (7%), while others (18.7%) were excluded by medical history and ECG findings.

The study population was divided into 5 groups according to their age (20-29 age group 1, 30-39 age group 2, 40-49 age group 3, 50-59 age group 4, and over 60 age group 5). The mean aortic elasticity parameters of the 5 groups were calculated. The groups were compared in terms of clinical, laboratory, and echocardiographic features.

The study was conducted in accordance with the Declaration of Helsinki and the study protocol was approved by the Ethics Committee of Koç University (Approval No: 2022.199.IRB1.076, Date: 30.05.2022).

Echocardiographic Evaluation

Transthoracic echocardiography was performed in lateral decubitus position using Epiq 7C ultrasound system (Philips, Andover, Mass, USA) equipped with a 2.3-3.5 MHz transducer probe with simultaneous ECG recording. Conventional measurements were made on images obtained from parasternal and apical windows after adjusting gain and frequency settings following the recommendations of the American Society of Echocardiography.[19] Left ventricular ejection fraction was calculated by the modified 2-dimensional biplane Simpson's method.[20] Left ventricular diastolic function was evaluated by trans-mitral velocities using pulsed wave Doppler and mitral annular velocities using tissue Doppler imaging.

Assessment of Aortic Elasticity Parameters

From parasternal long-axis images with M-mode echocardiography, ascending aorta recordings taken 3 cm above the aortic valve were used for measurements. Systolic aortic diameter (AoS) was measured at a fully open aortic valve position, while diastolic aortic diameter (AoD) was measured at the end of diastole at the peak of the QRS complex on the ECG recordings, from the distances between the anterior and posterior walls' inner edges of the vessel (Figure 1). Aortic elasticity parameters

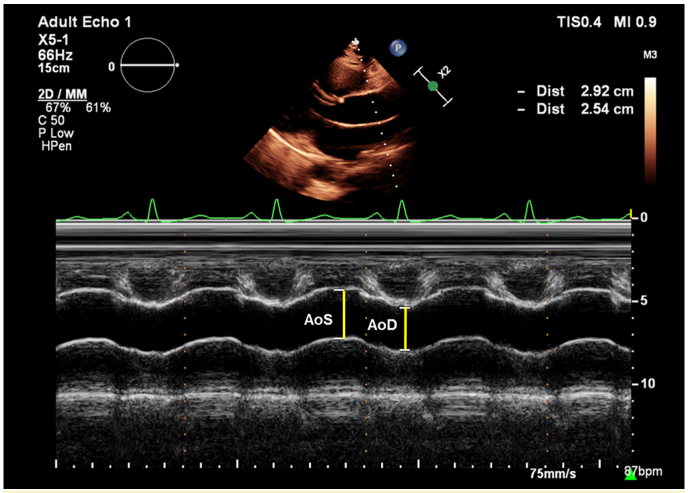

Figure 1. Parasternal long-axis view with M-mode echocardiography showing measurements of systolic aortic diameter (AoS) and diastolic aortic diameter (AoD) from the ascending aorta.

Table 1. Demographic and Laboratory Characteristics of the Study Group

Parameter	Study Group
Age (years)	42.18 ± 10.39
Female % (n)	54.3 (220)
BSA (m^2)	1.85 ± 0.21
Heart rate (bpm)	73.05 ± 10.61
SBP (mmHg)	113.31 ± 11.09
DBP (mmHg)	71.45 ± 7.24
LDL (mg/dL)	132.34 ± 34.75
HDL (mg/dL)	56.96 ± 16.14
Total cholesterol (mg/dL)	206.47 ± 40.37
Triglycerides (mg/dL)	110.89 ± 63.78
Smoking (%)/(n)	15.1 (61)

bpm, beat per minute; BSA, body surface area; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein; SBP, systolic blood pressure.

were calculated from the relevant formulas by using the systolic (SBP) and diastolic blood pressures (DBP) in addition to the aortic diameters. Pulse pressure was calculated by subtracting DBP from SBP.[10]

Aortic strain (%) = 100 × (AoS – AoD)/AoD

Aortic stiffness index = ln (SBP/DBP)/aortic strain

Aortic distensibility ($cm^2/dyn^1/10^3$) = 2 × aortic strain/pulse pressure

Statistics

The statistical software package Statistical Package for Social Sciences version 26.0 (SPSS Inc., USA) was used to evaluate the data obtained from the study. The normality of the distribution was determined by the Kolmogorov-Smirnov test. Results are described as numbers and percentages for categorical variables and mean ± standard deviation for continuous variables. The mean values of the variables in the age groups were compared with the one-way ANOVA test. Student's t-test was used to compare the means of variables in the 2 groups. The chi-square test was used to compare categorical variables. The P-value less than 0.05 was considered statistically significant. In the correlation analyses, the Pearson test was used for continuous variables, while Spearman's correlation was used for ordinal data and the correlation coefficient (r) was calculated. Multivariate linear regression analyses were performed to identify independent determinants of aortic elasticity parameters.

Results

The study included 405 subjects (mean age 42.18 ± 10.39, 54.3% female). Baseline demographic and laboratory features of the study group were demonstrated in Table 1. The mean aortic strain value was found to be 15.14% ± 3.56, mean aortic stiffness index was 3.24 ± 1.05, and mean aortic distensibility was 7.48 ± 2.36 $cm^2/dyn^1/10^3$ (Figure 2A). Conventional echocardiographic evaluations along with these measurements are shown in Table 2.

In groups classified according to age, basic demographic and clinical features were found to be similar, except for Body Surface Area (BSA) and pulse pressure (Table 3). Aortic strain and distensibility values significantly decreased with increasing age groups, while aortic stiffness index significantly increased (Figure 2B). Left ventricular diastolic parameters E and A wave velocities, E/A ratio, and E' wave velocity were found to be significantly lower by increasing age, while DT, IVRT, and E/E' values were significantly higher (Table 4).

Aortic strain and stiffness values did not differ between genders, while aortic distensibility was observed to be significantly higher in women than in men in the study group (15.41 ± 3.6 and 14.8 ± 3.41, $P = 0.095$; 3.16 ± 1.05 and 3.33 ± 1.05, $P = 0.112$; 7.93 ± 2.57 and 6.95 ± 1.95, $P < 0.001$, respectively). Considering the age groups, while aortic distensibility was significantly higher in women than in men in groups 3 and 4, this significant difference was not observed in groups 4 and 5. Aortic stiffness index was significantly lower, strain was significantly higher in women in group 2 compared to men. This difference disappeared in increasing age groups (Figure 3).

In pairwise comparisons made between the groups by post hoc Bonferroni analysis, aortic strain was found to be significantly higher in the youngest group (group 1) than in all other groups while showing no significant difference between consecutive paired groups. The aortic stiffness index was significantly lower in groups 1 and 2 than in groups 4 and 5, and significantly lower in groups 3 and 4 than in group 5. Aortic distensibility, on the other hand, did not show a significant difference between consecutive paired groups but was significantly higher in younger groups (Table 5).

Correlation analyses showed that all 3 aortic elasticity parameters were strongly correlated to age (Figure 4), aortic strain was weakly correlated with BSA and blood pressure values. In addition, there was a weak association between aortic stiffness and gender (higher in males), while aortic distensibility

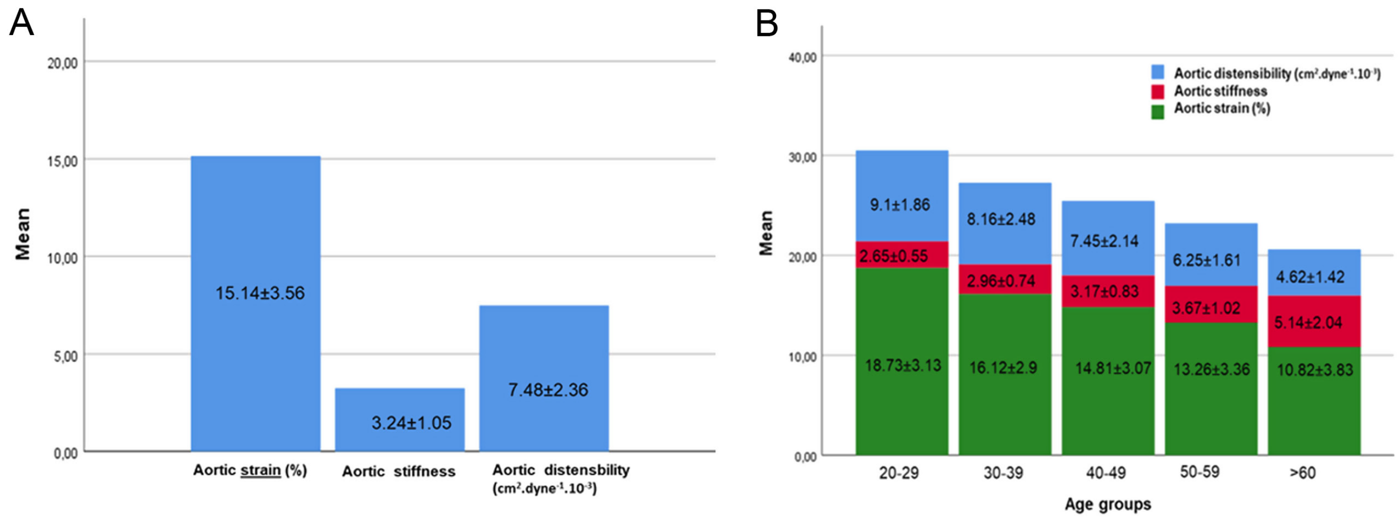

Figure 2. Mean values of aortic elasticity parameters. (A) In the study group. (B) In the age groups.

was strongly associated with gender (lower in males) and BSA (Table 6). Among the echocardiographic measurements, aortic elasticity parameters were significantly correlated with LV wall thicknesses, left atrial diameter, and all parameters related to diastolic functions.

Table 2. Echocardiographic Measurements and Aortic Elasticity Parameters of the Study Population

Parameter	Study Group
IVS (cm)	0.88 ± 0.07
PW (cm)	0.86 ± 0.07
LVEF (%)	60.88 ± 1.6
LVEDD (mm)	45.64 ± 3.17
LVESD (mm)	29.42 ± 2.56
LA diameter (mm)	35.66 ± 1.72
RA diameter (mm)	34.28 ± 1.98
RV diameter (mm)	32.59 ± 2.3
sPAP (mmHg)	22.62 ± 2.78
E wave velocity (cm/s)	79.52 ± 12.74
A wave velocity (cm/s)	66.514 ± 11.79
E/A ratio	1.21 ± 0.22
IVRT (ms)	89.45 ± 7.16
DT (ms)	173.77 ± 25.28
E' (cm/s)	14.31 ± 2.76
E/E' ratio	5.66 ± 1.007
AoS (mm)	29.69 ± 2.96
AoD (mm)	25.84 ± 3.04
Aortic strain (%)	15.14 ± 3.56
Aortic stiffness	3.24 ± 1.05
Aortic distensibility (cm^2/dyne^1/10^3)	7.48 ± 2.36

AoD, diastolic aortic diameter; AoS, systolic aortic diameter; DT, deceleration time; IVRT, isovolumic relaxation time; LA, left atrium; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic diameter; RA, right atrium; RV, right ventricle; sPAP, systolic pulmonary artery pressure.

In the multivariate linear regression analysis, while age was an independent risk factor for all aortic elasticity parameters, BSA was revealed as an independent risk factor for aortic distensibility (Table 7).

Discussion

In this study, normal values of aortic elasticity parameters were evaluated by transthoracic echocardiography in a normotensive population without overt CVD. Also, since age is the most important determinant of these parameters, the study population was evaluated in the 5 age group. A significant increase in aortic stiffness and a significant decrease in aortic distensibility and strain were observed with age. Considering the age groups with 10-year intervals, there was no significant difference between consecutive groups at younger ages, but a significant increase was observed in groups with 10-year intervals from the age of 40 onward.

Arterial elastic properties have been shown to deteriorate with age regardless of other CV risk factors.[21] Aortic strain represents a circumferential deformation index determined by the dynamic change in aortic diameters during the cardiac cycle. While aortic distensibility indicates the ability of the vessel wall to comply with pulsatile blood flow by stretching, aortic stiffness defines the resistance of the vessel wall to blood pressure.[22,23] In our study, correlation and regression analyses showed that aortic elasticity parameters are closely related to age, and age is an independent risk factor for all three parameters. Studies with PWV, mostly in large arteries, have shown that this increase becomes more pronounced after 55 years of age.[24,25] In a study by Kılıç,[26] investigating the reference values of brachial PWV, a significant increase in PWV was found after the age of 50. Similarly, in our study, a significant impairment was observed in aortic stiffness, especially after the age of 50, and the greatest difference was seen in the group after 60 years of age. One of the suggested mechanisms for this is the increase in pulse pressure with age and the development of systolic hypertension.[27] In our research,

Table 3. Comparison of Demographic and Laboratory Features of the Groups

Parameter	Group 1 (n=40)	Group 2 (n=130)	Group 3 (n=143)	Group 4 (n=71)	Group 5 (n=21)	*P*
Age	24.8 ± 3.32	35.33 ± 2.87	44.19 ± 2.66	54.26 ± 2.79	65.09 ± 4.86	**<0.001**
Female % (n)	50 (20)	55.4 (72)	75 (52.4)	56.3 (40)	61.9 (13)	0.884
BSA (m^2)	1.83 ± 0.24	1.86 ± 0.22	1.87 ± 0.21	1.82 ± 0.17	1.82 ± 0.17	**0.024**
SBP (mmHg)	109.12 ± 9.79	111.67 ± 11.28	113.21 ± 10.80	116.69 ± 10.24	120.71 ± 11.43	0.606
DBP (mmHg)	67.12 ± 6.59	70.45 ± 6.79	72.27 ± 7.30	73.73 ± 7.25	72.61 ± 71.45	0.365
Pulse pressure (mmHg)	42 ± 7.23	41.22 ± 7.86	40.93 ± 6.51	42.95 ± 6.73	48.09 ± 8.58	**<0.001**
Heart rate (bpm)	74.45 ± 14.49	74.14 ± 9.91	73.07 ± 10.22	71.59 ± 9.95	68.15 ± 9.85	0.922
LDL (mg/dL)	106.91 ± 24.10	129.86 ± 34.26	134.40 ± 34.72	143.05 ± 34.59	128.09 ± 34.94	0.485
HDL (mg/dL)	60.30 ± 17.63	55.33 ± 16.03	54.44 ± 15.11	61.87 ± 16.03	63.81 ± 18.59	0.641
Total cholesterol (mg/dL)	176.69 ± 29.72	201.91 ± 40.41	208.36 ± 37.46	222.43 ± 38.72	207.09 ± 57.09	0.434
Triglycerides (mg/dL)	82.73 ± 46.26	106.35 ± 71.72	119.32 ± 65.55	111.14 ± 48.84	122.54 ± 65.18	0.250
Hyperlipidemia % (n)	5 (2)	20.8 (27)	22.4 (32)	23.9 (17)	14.3 (3)	0.121
Smoking % (n)	15 (6)	18.5 (24)	12.6 (18)	15.5 (11)	9.5 (2)	0.668

bpm, beat per minute; BSA, body surface area; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein; SBP, systolic blood pressure.

Table 4. Evaluation of Aortic Elasticity Parameters According to Age Groups

Parameter	Group 1 (n=40)	Group 2 (n=130)	Group 3 (n=143)	Group 4 (n=71)	Group 5 (n=21)	*P*
Aortic strain %	18.73 ± 3.13	16.12 ± 2.9	14.81 ± 3.07	13.26 ± 3.36	10.82 ± 3.83	**<0.001**
Aortic stiffness	2.65 ± 0.55	2.96 ± 0.74	3.17 ± 0.83	3.67 ± 1.02	5.14 ± 2.04	**<0.001**
Aortic distensibility ($cm^2/dyn^1/10^3$)	9.1 ± 1.86	8.16 ± 2.48	7.45 ± 2.14	6.25 ± 1.61	4.62 ± 1.42	**<0.001**
IVS (cm)	0.84 ± 0.07	0.86 ± 0.07	0.89 ± 0.07	0.9 ± 0.08	0.9 ± 0.04	**<0.001**
PW (cm)	0.83 ± 0.07	0.85 ± 0.07	0.87 ± 0.07	0.89 ± 0.07	0.9 ± 0.04	**<0.001**
LVEDD (mm)	45.32 ± 3.14	45.50 ± 3.66	46.06 ± 3.01	45.38 ± 2.64	45.23 ± 2.50	0.408
LVEDS (mm)	29.37 ± 2.63	29.57 ± 2.89	29.49 ± 2.41	29.18 ± 2.33	28.95 ± 1.98	0.754
LVEF (%)	60.72 ± 1.99	60.88 ± 1.75	61.01 ± 1.33	60.88 ± 1.50	60.33 ± 1.79	0.433
LAD (mm)	35.32 ± 1.96	35.40 ± 1.88	35.86 ± 1.65	35.83 ± 1.46	36.04 ± 1.20	0.091
RAD (mm)	34.12 ± 2.10	34.13 ± 2.06	34.44 ± 2.03	34.12 ± 1.68	34.90 ± 1.60	0.363
RVD (mm)	32.37 ± 2.77	32.63 ± 2.42	32.67 ± 2.22	32.25 ± 1.86	33.42 ± 2.35	0.301
sPAP (mmHg)	22.87 ± 2.36	21.95 ± 2.48	22.65 ± 2.71	23.23 ± 2.95	24.09 ± 3.93	**0.002**
E wave velocity (cm/s)	88.40 ± 11.59	79.77 ± 11.62	79.28 ± 11.97	75.38 ± 12.53	76.09 ± 18.20	**<0.001**
A wave velocity (cm/s)	63.52 ± 10.07	62.37 ± 10.11	66.33 ± 11.21	70.23 ± 11.88	78.42 ± 15.20	**<0.001**
/A ratio	1.40 ± 0.21	1.29 ± 0.17	1.19 ± 0.19	1.09 ± 0.21	0.98 ± 0.22	**<0.001**
IVRT (ms)	84.48 ± 7.33	87.92 ± 6.35	89.61 ± 6.14	93.04 ± 7.31	94.61 ± 8.53	**<0.001**
DT (ms)	173.51 ± 25.10	167.96 ± 18.62	174.79 ± 24.21	180.16 ± 24.17	186.33 ± 33.03	**0.001**
E' (cm/s)	17.12 ± 2.46	15.26 ± 2.48	13.95 ± 2.26	12.73 ± 2.51	11.75 ± 2.20	**<0.001**
E/E' ratio	5.24 ± 0.70	5.33 ± 0.95	5.75 ± 0.96	6.03 ± 1.06	6.43 ± 0.88	**<0.001**

DT, deceleration time; IVRT, isovolumetric relaxation time; IVS, interventricular septal thickness; LAD, left atrial end-systolic diameter; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic diameter; PW, posterior wall thickness; RAD, right atrial end-systolic diameter; RVD, right ventricular end-diastolic diameter; sPAP, systolic pulmonary artery pressure.

although patients with HT were excluded from the study, the pulse pressure was found to be significantly higher in the group over 60 years of age compared to those in their 30s and 40s. We also showed that aortic strain and distensibility begin to decrease at earlier ages. In post hoc analyses, it was observed that aortic strain decreased significantly even between the third and fourth

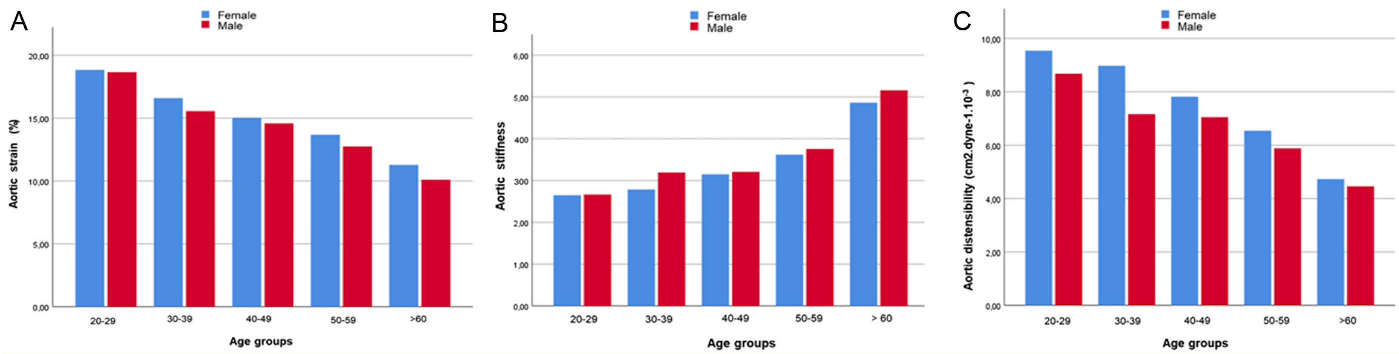

Figure 3. Graph of the mean values of aortic elasticity parameters in age groups by gender. (A) Aortic strain, (B) aortic stiffness, (C) aortic distensibility.

Table 5. Comparison of Aortic Elasticity Parameters Between Groups

Parameter	Groups		*P*	Parameter	Groups		*P*	Parameter	Groups		*P**
Aortic strain	1	2	**<0.001**	**Aortic stiffness**	1	2	0.633	**Aortic distensibility**	1	2	0.147
		3	**<0.001**			3	0.017			3	**<0.001**
		4	**<0.001**			4	**<0.001**			4	**<0.001**
		5	**<0.001**			5	**<0.001**			5	**<0.001**
	2	3	0.005		2	3	0.600		2	3	0.060
		4	**<0.001**			4	**<0.001**			4	**<0.001**
		5	**<0.001**			5	**<0.001**			5	**<0.001**
	3	4	0.006		3	4	**0.002**		3	4	0.01
		5	**<0.001**			5	**<0.001**			5	**<0.001**
	4	5	0.016		4	5	**<0.001**		4	5	0.022

**P* < 0.005 was considered significant according to post hoc Bonferonni correction for multiple comparisons.

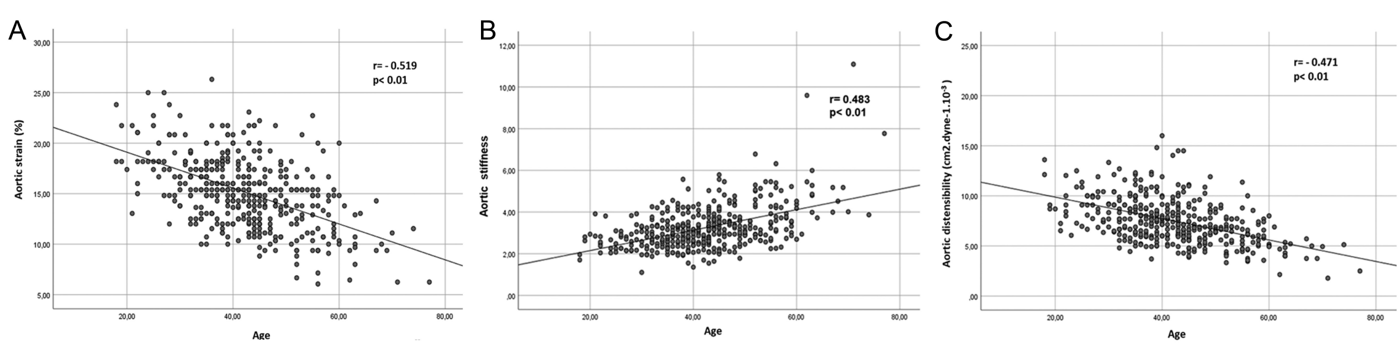

Figure 4. The correlation analysis between age and aortic elasticity parameters. (A) Aortic strain, (B) aortic stiffness, (C) aortic distensibility.

Table 6. Correlations Between Aortic Elasticity Parameters and Demographic Features

	Age	Gender	BSA	HL	Smoking	SBP	DBP
Aortic strain	**−0.519****	−0.083	**−0.102***	−0.049	−0.070	**−0.101***	**−0.119***
Aortic stiffness	**0.483****	**−0.105***	0.093	0.059	0.053	**0.228****	**−0.105***
Aortic distensibility	**−0.471****	**0.207****	**−0.242****	−0.074	−0.047	**−0.514****	**−0.169****

BSA, body surface area; DBP, diastolic blood pressure; HL, hyperlipidemia, SBP, systolic blood pressure.
**P* < 0.05; ***P* < 0.01.

Table 7. Multivariate Linear Regression Analysis for Aortic Elasticity Parameters

Variables	*B*	Standard Error	Beta	*t*	*P*
	Dependent variable		Aortic strain		
Age	−0.187	0.15	−0.548	−12.369	<**0.001**
Gender	−0.332	0.431	−0.047	−0.771	0.441
BSA	−2.04	1.754	−0.121	−1.972	0.05
HL	0.045	0.379	0.005	0.120	0.905
Smoking	−0.643	0.421	−0.065	−1.528	0.127
SBP	0.041	0.022	0.128	1.895	0.059
DBP	−0.024	0.032	−0.048	−0.747	0.456
	Dependent variable		Aortic stiffness		
Age	0.050	0.004	0.487	11.154	<**0.001**
Gender	0.081	0.132	0.038	0.617	0.538
BSA	0.418	0.311	0.083	1.343	0.180
HL	0.011	0.116	0.004	0.093	0.926
Smoking	0.051	0.129	0.017	0.394	0.694
	Dependent variable		Aortic elasticity		
Age	−0.109	0.010	−0.481	−11.386	<**0.001**
Gender	−0.392	0.284	−0.083	−1.377	0.169
BSA	−2.218	0.672	−0.198	−3.301	**0.001**
HL	−0.095	0.252	−0.016	−0.376	0.707
Smoking	−0.307	0.279	−0.047	−1.101	0.271

BSA, body surface area; DBP, diastolic blood pressure; HL, hyperlipidemia; SBP, systolic blood pressure.

decades. In parallel with our findings, Redheuil et al[28] demonstrated that aortic strain and distensibility examined with MRI decreased significantly before the age of 50 in asymptomatic subjects. The pathophysiological changes that occur in the arterial wall with age have revealed some hypotheses regarding this condition. Continuous pulsatile stress on the vessel wall causes thinning and fragmentation of elastin fibers in the early period. Decreased elastin synthesis and increased proteolysis reduce vascular strain and distensibility'. Later, the stiffness of the arterial wall increases with increased collagen deposition and fibrosis.[22,28] It has also been shown that calcium accumulates in the tunica media at older ages.[29] Current findings suggest that aortic strain and distensibility at earlier ages and aortic stiffness in older ages will be useful markers in determining CV risk.

It is suggested that genetic and dietary factors may also play a role in the relationship between age and aortic elasticity.[30] In a study by Avolio et al,[31] it was observed that a low sodium diet improved arterial distensibility measuring by aortic PWV in normotensive subjects. This effect was more pronounced in the group over 45 years of age than in the younger age group. In a study investigating genetic factors in the relationship between age and arterial elastic properties, Lajemi et al[25] showed that angiotensin II type 1 genotypes influenced the association of age and increased arterial PWV.

When the relationship between arterial elastic properties and gender is examined, age and blood pressure are important risk factors for both sexes. However, it has been shown that pulse pressure and arterial stiffness progress more rapidly with age in women and that the relationship between arterial stiffness and mortality is higher than in men.[32] The prevailing notion is that women have a protective effect of estrogen hormone in the premenopausal period and this effect gradually decreases after menopause and becomes similar to men.[33] In addition, some conditions specific to women or more common in women, such as obesity, metabolic syndrome, preeclampsia, polycystic ovarian syndrome, and autoimmune diseases, may be counted for the other mechanisms.[34,35] Consistent with these findings in our study, aortic stiffness was not found to be significantly different between men and women in the entire study group. Considering the age groups, aortic stiffness was significantly higher in men in group 2 (30-39 years of age), but this difference between the genders was not observed in the advancing age groups.

When the effect of aortic elastic properties on cardiac structure and functions is examined, augmented aortic stiffness increases afterload, causing LV hypertrophy and impaired LV diastolic functions. In our study, consistent with this pathophysiological mechanism, aortic elasticity parameters were found to be significantly associated with LV wall thickness, left atrial diameter, and diastolic function indices.

Various population-based research and studies in different risk groups have shown that increased arterial stiffness is independently associated with the development of CAD and both fatal and non-fatal adverse CV events.[36-38] Willum-Hansen et al[39] demonstrated that aortic stiffness is increased in normotensive children whose parents have HT, supporting that it is a risk factor for the development of CVD independent of other traditional risk factors. In previous studies, while it was assumed that HT increases arterial stiffness and thus contributes to the development of atherosclerosis, current findings indicate that increased arterial stiffness is the cause of HT rather than the consequences.[40,41] The Framingham Heart study and several meta-analyses have shown that arterial stiffness assessment may contribute to the identification of CV risk in addition to standard risk factors.[42-44] It was suggested that lifestyle changes and the use of ACE inhibitors can reduce arterial stiffness regardless of their effect on blood pressure in some research.[45] Cardiovascular risk, which is determined early by assessing arterial elasticity parameters, can be modified by some treatments and lifestyle changes regardless of other well-known risk factors. A substantial proportion of patients with CAD have either no classical risk factors or only one risk factor.[46] In light of all these data, it is substantial to establish the reference values of these parameters in identifying patients with increased risk regardless of other risk factors.

In conclusion, due to the association of impaired aortic elastic properties with the development of CV disease and increased mortality and morbidity, it becomes important to determine the normal values of aortic elasticity parameters and to evaluate them according to age groups. Aortic elasticity parameters can be readily evaluated with echocardiography in daily practice.

Comparing these measurements with normal values in similar age groups may help to detect patients with increased CV risk in the early period, regardless of the other risk factors.

The major limitation of the study is that it was conducted in a single center. Although the number of patients enrolled is satisfactory, the fifth group includes relatively few individuals due to broad exclusion criteria. In addition, the calculation of aortic elasticity parameters by TTE using the relevant formulas is an indirect method. However, TTE also has some advantages in that it is a more widely used easy method and allows the evaluation of 3 different parameters. Another limitation of the study is that the selection of normotensive subjects was made based on the HT and anti-HT treatment history and BP measurements made in the cardiology outpatient clinic and before the echocardiographic examination, not according to ambulatory BP monitoring.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Koç University, (Approval Number: 2022.199.IRB1.076, Date: 30.05.2022).

Informed Consent: Written informed consent was obtained from the patients who agreed to take part in the study.

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