Atrial Functions and Aortic Elasticity in Children with Aortic Coarctation

Savas Demirpence,1 Baris Guven,2 Murat Muhtar Yilmazer,1 Taliha Oner,1 Onder Doksoz,1 Timur Mese1 and Vedide Tavli2

Background: Coarctation of the aorta (CoA) is a chronic vascular disease characterized by a persistence of myocardial and vascular alterations. We aimed to evaluate children who have had successful coarctation surgery or balloon dilatation to evaluate the elasticity of the aorta, left atrial ejection force (AEF) and myocardial performance collectively at midterm follow-up.

Methods: Nineteen patients (7.15 ± 0.9 years of age) and 21 age-sex matched healthy children were included in this study. Left AEF index is defined as the product of mass and acceleration of blood expelled from the left atrium. Aortic stiffness and distensibility were estimated using ascending and descending aorta diameters.

Results: The left atrial force index [(g cm/s²)/m²] in the patient group was found to be significantly higher (12.69 ± 7.29, 5.74 ± 2.59, respectively, p = 0.001). Distensibility of the ascending aorta (cm²/dynes 10⁻⁶) was significantly lower in the patient group than in the control group (42.13 ± 24.02, 78.79 ± 20.49, respectively, p < 0.001). The stiffness index of the ascending aorta was significantly higher in the patient group (p < 0.001). We also documented that atrial force index is associated with peak E velocity, right arm systolic blood pressure and left ventricular mass index.

Conclusions: Our investigation showed that AEF is higher in children who have had successful coarctation surgery or balloon dilatation, and AEF is associated with systolic blood pressure, peak E velocity and left ventricular mass index. Distensibility of the ascending aorta was lower, and stiffness index was higher in children with corrected CoA than in healthy subjects.

Key Words: Atrial ejection force • Balloon dilatation • CoA • Coarctation surgery • Distensibility • Stiffness index

INTRODUCTION

Coarctation of the aorta (CoA) is one of the most common congenital heart defects that generally requires interventional catheterization or surgery during the first year.1 Despite successful surgical and interventional therapeutic options, it is still currently considered as a chronic disease due to problems of late morbidity and mortality.2 Cohen et al.3 demonstrated that survival following surgery of aortic coarctation is associated with patient age at the time of operation. From the findings of previous studies, it was suggested that coronary artery disease, stroke, sudden cardiac death and late hypertension may alter the survival and the outcome of aortic coarctation.4,5 It was also shown that precoarctated arterial bed abnormalities following corrective surgery in patients with CoA cause persistent hypertension and increased left ventricular mass.6 The mechanisms including secondary hyperactivation of the renin-angiotensin system, impaired baroreflex sensitivity as well as abnormal peripheral vascular reactivity...
have been implicated as underlying causes for hypertension.9,10 Recently, evaluation of ventricular diastolic function is becoming progressively essential in the management of children with cardiac diseases. It is well-known that left ventricular diastolic filling abnormalities may precede the impairment of left ventricular systolic function.11 Left ventricular diastolic function influences left atrial contraction. In other words, left ventricular diastolic function is the reflection of the left atrial afterload. AEF was initially defined by Manning et al.12 in 1993 as a Doppler-derived parameter for assessment of atrial mechanical function following cardioversion. Until now, no data regarding AEF in children with repaired coarctation of aorta have been available. Therefore, we conducted a study focusing on children who have had successful coarctation surgery or balloon dilatation to evaluate the elasticity of aorta, left AEF and myocardial performance collectively at midterm follow-up.

MATERIALS AND METHODS

Patients

Nineteen children with CoA who were admitted to our pediatric cardiology institute between August 2009 and October 2010 were prospectively included in the study (without significant associated cardiovascular defects, such as ventricular septal defects and aortic valve abnormalities). Clinical characteristics of patients are presented in Table 1. Those who had neither abnormalities of the heart or great vessels nor evidence of recoarctation13 (20 mm Hg and/or 3.5 m/s velocity pressure gradient at continuous wave Doppler echocardiography within the aortic arch and the presence of diastolic tail) at the last outpatient visit were asked to join the study. The mean repair age of the study group was 16.90 ± 24.79 months (range 2 to 84 months). The mean follow-up duration was 4.48 ± 1.57 years (range 3 to 8 years). Four patients subsequently experienced balloon angioplasty or surgery due to recoarctation. Of these, in one patient, balloon angioplasty was needed after the second patch aortoplasty. No child who had successful balloon angioplasty developed an aneurysm. Eleven patients had been using either beta blocker or ACE inhibitors at the time of a study. There were 21 healthy children matched for age and sex included in this study. Written informed consent was taken from all the parents, and all data were processed according to the 1975 Helsinki Declaration.

Study protocol

Blood pressure measurement

Clinical parameters were gathered on the day of echocardiographic assessment together with records of weight, height, heart rate, systolic blood pressure and diastolic blood pressure. After five minutes of resting, blood pressure measurements were taken in the right arm from all subjects using an automated blood pressure cuff. An appropriately sized blood pressure cuff with a width ≥ 2/3 of the upper arm or the calf was used.14 For analysis, the mean of three measurements was obtained. Hypertension was defined as an average systolic or diastolic blood pressure of greater that or equal to the 95th percentile for age, sex and high percentile according to the Task Force on Blood Pressure Control in Children.14 The difference between systolic and diastolic blood pressures was accepted as an esti-

<table>
<thead>
<tr>
<th></th>
<th>Patient group</th>
<th>Healthy subjects</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female</td>
<td>9/10</td>
<td>10/11</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>7.15 ± 0.9</td>
<td>8.00 ± 0.67</td>
<td>0.23</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>25.58 ± 3.36</td>
<td>27.33 ± 2.66</td>
<td>0.16</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>121.37 ± 5.27</td>
<td>123.19 ± 4.44</td>
<td>0.70</td>
</tr>
<tr>
<td>Heart rate</td>
<td>94.58 ± 13.3</td>
<td>89.68 ± 6.52</td>
<td>0.12</td>
</tr>
<tr>
<td>Blood pressure (mmHg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right arm systolic</td>
<td>108.11 ± 2.05</td>
<td>106.76 ± 1.24</td>
<td>0.48</td>
</tr>
<tr>
<td>Right arm diastolic</td>
<td>66.21 ± 1.35</td>
<td>69.48 ± 1.21</td>
<td>0.08</td>
</tr>
<tr>
<td>Right leg systolic</td>
<td>111.47 ± 1.94</td>
<td>113.10 ± 1.26</td>
<td>0.44</td>
</tr>
<tr>
<td>Right leg diastolic</td>
<td>65.11 ± 2.91</td>
<td>70.57 ± 4.9</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Table 1. Clinical characteristics of study groups
mation of aortic pulse pressure.\textsuperscript{15}

**Echocardiographic studies**

Echocardiograms were obtained with Vivid 3 Ultrasound system utilizing 3- and 5-megahertz phased array transducers (General Electric). Successful imaging of the aortic arch was possible from the suprasternal approach in all cases. A peak instantaneous pressure gradient was determined from the maximal flow velocity using the modified Bernoulli equation. The presence or absence of a diastolic tail was observed. Left ventricular mass (LVM) measured by two-dimensional directed M-mode echocardiography according to the American Society of Echocardiography criteria.\textsuperscript{16} LVMI [LV mass/height raised to a power of 2.7 (g/m$^{2.7}$)] was applied to evaluate left ventricular hypertrophy (LVH) accounting for body size, as described previously.\textsuperscript{17} The LVMI $\geq$ 38.6 g/m$^{2.7}$ in all subjects was accepted as LVH.\textsuperscript{18} Systolic properties of the left ventricle were assessed by estimation of shortening fraction (SF) and velocity of circumferential fiber shortening (VCFc). VCFc, mean rate corrected velocity of circumferential fiber shortening was calculated by dividing fractional shortening by the rate-corrected ejection time (ET). ET is the left ventricular ejection time measured from the outflow velocity curve obtained by pulse wave Doppler sampling at the level of the aortic valve.\textsuperscript{19} End-systolic wall stress (ESS), an index of afterload, was calculated as follows: $1.35 \times \text{Pes} \times \text{Ds}/(4 \times \text{PWs}) \times (1 + \text{PWs}/\text{Ds})$. Additionally, 1.35 was the conversion factor from mmHg to g/cm\textsuperscript{2}, and Pes was the branchial arterial cuff peak systolic blood pressure in mmHg. Ds and PWs are end-systolic dimension and wall thickness (in centimetres), respectively.

**Diastolic functions and Tei index**

From the apical four chamber view, transmitral pulsed Doppler examination of the left ventricular inflow tract was obtained at the level of the mitral valve annulus and the maximal velocities recorded. From the digitalized Doppler spectral tracings, peak E (passive filling phase of the mitral inflow velocity) and A (active filling phase of the mitral inflow velocity) velocities and the areas under the Doppler tracings were measured.\textsuperscript{20} Myocardial performance index (MPI), also denoted as Tei index,\textsuperscript{21} was designated to be the sum of isovolumic contraction time and isovolumic relaxation time divided by the ejection time. Isovolumic contraction time was defined as the interval between the end of the mitral inflow and the onset of left ventricular outflow; isovolumic relaxation time was measured as the interval between left ventricular outflow velocity and the onset of mitral flow.

**Calculation of vascular parameters**

In order to assess the diameter changes of ascending and descending aorta, M-mode tracings were recorded concurrently with an electrocardiogram at 2 different levels as described previously.\textsuperscript{22} Measurement of the ascending aorta was achieved in a parasternal long-axis view at the level of the proximal ascending aorta 5 mm superior to the sinotubular junction, while descending aorta was assessed in an abdominal paramedian long axis view just proximal to the branching off of the celiac trunk. All images were digitally stored as JPEG and AVI data in the computer. We used image processing software (OsirIX) for calculation of parameters, m-mode recordings of ascending and descending aorta at least five heart cycles were inserted into the program. Images were enlarged with the purpose of elucidation of the inner boundaries of the aortic wall using software.

From these systolic and end-diastolic diameters and average of blood pressure measurements, aortic elastic parameters, such as distensibility and stiffness index were calculated using the following formulas:

\[
\text{Distensibility} = \frac{(\text{As} - \text{Ad})}{\text{Ad} \cdot \left(\frac{\text{Ps} - \text{Pd}}{1333}\right)} \cdot 10^7 (10^{-3} \text{kPa})
\]

\[
\text{Stiffness index} = \frac{\ln(\text{Ps}/\text{Pd})}{\left(\frac{\text{Ds} - \text{Dd}}{\text{Dd}}\right)} \text{ (dimensionless)}
\]

In these formulas, As is systolic, Ad is the end-diastolic area in mm$^2$ and Ps is systolic and Pd is diastolic blood pressure in mmHg. Area (A) was defined as $(D/2)^2 \times \pi$.

Intraobserver variability was determined by calculating the arithmetic and absolute differences between repeated measurements; conversely, interobserver variability was estimated by comparing the measurements of the 2 observers.

**Determination of left AEF**

AEF was determined using a formula previously described. Manning et al.,\textsuperscript{12} used Newton’s second law of
motion by which Force = Mass × acceleration. Mass is described as the product of density of the blood (ρ) and the blood volume passing through the mitral inflow during atrial contraction. Mitral valve diameter (d) was taken from an apical 4-chamber view and mitral valve area was calculated as π d²/4, assuming that the shape of the annulus would be circular. Acceleration of blood throughout atrial contraction is found as acceleration of blood = peak A velocity/time to peak A velocity, replacing these variables in Newton’s formula:

\[ \text{Atrial ejection force} = \text{Mitrval valve area} \times (\text{peak A velocity})^2 \times 0.5 \times \rho \]

The units of force would therefore be measured in dynes or g·cm/s². AEF was divided by body surface area defined as AEF index.

Statistical analysis

Data analysis was performed with SPSS version 13 software for Windows. Data are presented as mean ± SD. The comparison of groups of continuous variables was achieved by Student’s t-test and, in case of skewed distribution of a variable, by use of the Mann-Whitney test. The discrete variables were expressed as absolute values and percentages and were compared using χ² test. Spearman’s correlation was used to determine the relation between several clinical and echocardiographic variables and left atrial force and elastic properties of aorta. A p value less than 0.05 was considered to be statistically significant.

RESULTS

Study population

There were no significant differences with respect to age at the time of study, weight, height and gender between patients and healthy subjects (Table 1). Resting blood pressure in the right arm and leg and heart rate did not differ significantly between patients and healthy subjects (Table 2). Two patients of the study group had a systolic and diastolic blood pressure above the 95th percentile for gender, age and height. Results of M-mode echocardiography showed that only interventricular septum thickness was significantly higher in the patient group. Ejection fraction and fractional shortening were not different between the two groups. There were no significant differences between the groups according to

| Table 2. Type of treatment, age at repair and pre and post repair pressure gradients of patient group |
|---------------------------------------------------|---------------------------------|-----------------|-----------------|
| Case | Type of treatment | Age at repair | Mean Pressure gradients (at the CoA site) pre and post repair (m/s) |
| 1 | Balloon angioplasty (BA) | 3 m | 3.71 | 1.94 |
| 2 | End to end anastomose | 2 m | 3.84 | 1.58 |
| 3 | LSCA flap aortoplasty | 4 m | 3.71 | 1.94 |
| 4 | End to end anastomose | 3 m | 3.54 | 1.80 |
| 5 | End to end anastomose | 3 m | 3.94 | 1.73 |
| 6 | BA + Patch aortoplasty 2 times | 1.5 months, 2.5 ψ, 8 ψ | 4.18 | 2.50 |
| 7 | Balloon angioplasty | 2 ψ | 3.71 | 1.87 |
| 8 | Balloon angioplasty | 3 ψ | 3.81 | 1.66 |
| 9 | Balloon angioplasty | 23 d | 3.46 | 1.87 |
| 10 | Balloon angioplasty | 4 ψ | 3.87 | 2.29 |
| 11 | Balloon angioplasty | 4 ψ | 4.30 | 2.29 |
| 12 | Balloon angioplasty | 4 ψ | 4.24 | 2.12 |
| 13 | End to end anastomose + BA | 3 m, 2 ψ | 3.81 | 2.60 |
| 14 | End to end anastomose + BA | 2 m, 1.5 ψ | 3.67 | 2.35 |
| 15 | Balloon angioplasty | 3 m | 3.91 | 1.87 |
| 16 | LSCA flap aortoplasty | 7 ψ | 4.03 | 1.80 |
| 17 | BA + End to end anastomose | 2 ψ, 3 ψ | 4.06 | 1.94 |
| 18 | Balloon angioplasty | 1.5 ψ | 3.81 | 1.94 |
| 19 | End to end anastomose | 3 m | 3.67 | 2.12 |

BA, balloon angioplasty; CoA, coarctation of the aorta; LSCA, left subclavian artery.
fractional shortening, end systolic stress and velocity of circumferential fiber shortening. The MPI (Tei index) was higher in the patient group than in the control group. Additionally, the LVMI in the patient group was significantly higher compared with that in the control group. The data presented in Table 3 showed that the differences in left ventricular diastolic function parameters such as peak E velocity, peak A velocity and isovolumic relaxation time (IVRT) were statistically significant (p < 0.05). Seven members of the patient group had bicuspid valves, but there was no aortic flow abnormality observed. None of the patient group had hypoplastic ascending aorta. There was no proof of residual obstruction at the CoA site, described as a continuous wave Doppler peak velocity at the CoA site exceeding 3.5 m/s (2.01 ± 0.09) or systolic blood pressure gradient between the right arm and leg greater than 20 mmHg. None of the patients had a diastolic tail.

Elasticity and stiffness index

M-mode recordings of aorta demonstrated that distensibility of the ascending aorta was significantly lower in the patient group than in the control group (Table 4). Likewise, the stiffness index of the ascending aorta was significantly higher in the patient group. There were no statistically significant differences between the two groups in terms of distensibility and stiffness index of the descending aorta.

Left atrium properties

There were statistically significant differences between the two groups by means of AEF and AEF index (Table 4). Correlation analyses of clinical and echocardiographic parameters and atrial force index and elastic properties of ascending aorta in the patient group are displayed on Table 5. We found that atrial force index is correlated with peak E velocity, left ventricular end diastolic diameter (LVEDD), left ventricular posterior wall end diastolic diameter, right arm systolic blood pressure and LVMI. Intraobserver variability and interobserver variability were 7.2 % and 7.8 %, respectively.

**DISCUSSION**

Consistent with previous reports,22,23 our findings showed that distensibility of the ascending aorta was lower, and the stiffness index was higher in patients with corrected CoA than in healthy subjects. We also attempted to investigate the relationship between atrial

**Table 3.** Comparison of left ventricular systolic and diastolic functions between patient and control groups

<table>
<thead>
<tr>
<th></th>
<th>Patient group (n:19)</th>
<th>Control group (n:21)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak E (m/s)</td>
<td>1.19 ± 0.17</td>
<td>0.92 ± 0.08</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Peak A (m/s)</td>
<td>0.85 ± 0.18</td>
<td>0.52 ± 0.85</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>E/A</td>
<td>1.43 ± 0.26</td>
<td>1.99 ± 0.35</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>DT (ms)</td>
<td>144.26 ± 5.38</td>
<td>90.38 ± 7.64</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>IVRT (ms)</td>
<td>62.58 ± 2.58</td>
<td>51.57 ± 3.23</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>ICT (ms)</td>
<td>64.12 ± 4.27</td>
<td>52.35 ± 3.61</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>FS (%)</td>
<td>0.39 ± 0.05</td>
<td>0.36 ± 0.03</td>
<td>0.12*</td>
</tr>
<tr>
<td>VcFc (circ/sn)</td>
<td>1.27 ± 0.19</td>
<td>1.15 ± 0.12</td>
<td>0.09*</td>
</tr>
<tr>
<td>ESS</td>
<td>74.47 ± 7.34</td>
<td>72.09 ± 7.58</td>
<td>0.41*</td>
</tr>
<tr>
<td>MPI</td>
<td>0.45 ± 0.04</td>
<td>0.34 ± 0.02</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Values are mean ± SD. A, active filling phase of the mitral inflow velocity; DT, deceleration time; E, passive filling of the mitral inflow velocity; ESS, end systolic wall stress; FS, fractional shortening; ICT, isovolumic contraction time; IVRT, isovolumic relaxation time; MPI, myocardial performance index; VcFc, velocity of circumferential fiber shortening; * Indicates student’s t test, * Indicates Mann Whitney U test.

**Table 4.** Comparison of elastic properties of aorta and atrial force parameters between patient and control groups

<table>
<thead>
<tr>
<th></th>
<th>Patient group (n = 19)</th>
<th>Control group (n:21)</th>
<th>p value</th>
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</thead>
<tbody>
<tr>
<td>Asc Ao D (kpa⁻¹ 10⁻³)</td>
<td>42.13 ± 24.02</td>
<td>78.79 ± 20.49</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Asc Ao SI</td>
<td>5.12 ± 1.24</td>
<td>2.57 ± 0.68</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Des Ao D (kpa⁻¹ 10⁻³)</td>
<td>85.30 ± 28.10</td>
<td>88.74 ± 31.15</td>
<td>0.38*</td>
</tr>
<tr>
<td>Des Ao SI</td>
<td>2.67 ± 1.02</td>
<td>2.36 ± 1.13</td>
<td>0.28*</td>
</tr>
<tr>
<td>Atrial ejection force</td>
<td>10.16 ± 3.93</td>
<td>4.81 ± 1.19</td>
<td>0.003*</td>
</tr>
<tr>
<td>Atrial ejection force index</td>
<td>12.69 ± 7.29</td>
<td>5.74 ± 2.59</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

Values are mean ± SD. Ao, aorta; Asc, ascending; D, distensibility; Des, descending; SI, stiffness index; * Indicates Mann Whitney U test.
force index and left ventricular functions, blood pressure and age at operation in patients who have had successful coarctation surgery or balloon dilatation. Although some features have been covered by earlier research, to the best of our knowledge we are to first to evaluate AEF and aorta elasticity and their relationships reciprocally and with age at operation, clinical and echocardiographic aspects in children with CoA. The present study provides evidence that AEF is higher in children with CoA and is associated with blood pressure, peak E velocity, diastolic left ventricular posterior wall thickness, LVEDD and LVMI.

It is well known that the left atrium plays an important role in left ventricular filling. Initially, the left atrium acts as a reservoir of expansion through systole, then as a conduit phase during diastole and finally as an active phase in late diastole. This active phase has an essential role in compensation of decreased left ventricular compliance in patients with heart failure. Besides this physiological aspect, left atrial function is also an independent factor of prognosis in cases with heart failure. Increased AEF and left atrial volume has been proven as a strong determinant of cardiovascular events in recent population-based cohort studies. There are also several disorders that are associated with increased AEF, including hypertrophic cardiomyopathy, autoimmune diseases, hypertension and age-linked myocardial stiffness. However, the role of this Doppler-derived parameter in the evaluation of children with CoA is not well known. Chinali et al. showed that augmented left atrial force determines hypertensive patients with greater LVM and prevalence of LVH. Likewise, in our study, we documented that the atrial force index is influenced by peak E velocity, right arm systolic blood pressure and especially LVMI. Previous studies with hypertensive adult patients suggested that increased LVM, developing as an adaptive mechanism in the background of increased afterload, may be accountable for the pathologic manifestations of hypertensive cardiovascular disease. Leandro et al. have proposed that successfully treated aortic coarctation children who are normotensive at rest after operation are still at risk for developing end organ damage, which is most likely explained by the onset of mild hypertension recorded by ambulatory blood pressure monitoring. Doppler derived transmitral velocity as a measure of diastolic function is altered initially in patients with diastolic hypertension. The findings of these adult studies also indicate that impaired diastolic functions precede the occurrence of obvious LVH and may persist despite effective blood pressure control. In the current study, increased left atrial ejection force and E velocity are reliable with increased raised left atrial pressure or decreased left ventricular relaxation. Originally, left atrial force is mostly dependent on peak A velocity. However, we found a relationship between LAEF and E wave. This finding could be explained by mutual interactions of both waves, or factors which may alter diastolic filling. It is also known that atrial early and late diastolic waves are directly related with left ventricular

### Table 5. Correlation analysis of clinical and echocardiographic parameters and atrial force index and elastic properties of ascending aorta in patient group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation with atrial force index</th>
<th>Correlation with distensibility of ascending aorta</th>
<th>Correlation with stiffness of ascending aorta</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>p</td>
<td>R</td>
</tr>
<tr>
<td>Age at operation</td>
<td>-0.27</td>
<td>0.14</td>
<td>-0.08</td>
</tr>
<tr>
<td>Right arm systolic blood pressure</td>
<td>0.58</td>
<td>0.02</td>
<td>-0.41</td>
</tr>
<tr>
<td>E wave</td>
<td>0.56</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>E/A ratio</td>
<td>-0.59</td>
<td>0.01</td>
<td>0.30</td>
</tr>
<tr>
<td>Tei index</td>
<td>0.02</td>
<td>0.93</td>
<td>0.33</td>
</tr>
<tr>
<td>LVEDd</td>
<td>-0.51</td>
<td>0.04</td>
<td>-0.19</td>
</tr>
<tr>
<td>LVPWd</td>
<td>0.53</td>
<td>0.03</td>
<td>-0.16</td>
</tr>
<tr>
<td>LVMI</td>
<td>0.60</td>
<td>0.009</td>
<td>-0.13</td>
</tr>
</tbody>
</table>

Spearman’s correlation was used to examine the correlation between the variables and atrial force index and elastic properties of ascending aorta. R indicates correlation coefficient; p, significance of correlation. A, active filling phase of the mitral inflow velocity; E, passive filling of the mitral inflow velocity; LVEDd, left ventricular end diastolic diameter; LVMI, left ventricular mass index; LVPWd, left ventricular posterior wall end diastolic diameter.
relaxation and left ventricular filling pressures. In the current study, the patient group had significantly higher E and A wave readings. We found that parameters of mitral valve deceleration time, isovolumetric relaxation time and isovolumetric contraction time were increased in the patient group. Changes in these parameters can be explained by reduced ventricular compliance, likely resulting from ventricular hypertrophy. LVH is documented by a prolonged deceleration and isovolumetric relaxation times. Ventricular compliance progressively lessens, together with unremitting abnormality in ventricular relaxation. Left atrial pressure increases to preserve left ventricular filling as a consequence of reduced compliance or increased stiffness of the left ventricle. Subsequently, the Frank-Starling mechanism is activated in the left atrium to increase contractility, systolic force and work by expanding the chamber. Additionally, we observed that the MPI in the study group was higher than that in the healthy subjects. The MPI, also known as the Tei index, is a valid echocardiographic parameter due to its facility to assess general left ventricle performance. This index is less dependent on ventricular geometry and preload, is more sensitive than endocardial methods and transmitral Doppler flow imaging that are accessibly used to evaluate left ventricular function. It has been shown that MPI was correlated well with the left ventricular systolic and diastolic functions, which were measured invasively by cardiac catheterization. The first study that evaluated MPI in 40 children who underwent repair of aortic coarctation showed that the MPI was abnormal in 47.5% of patients. Additionally, we observed that the MPI in the study group was higher than that in the healthy subjects. The MPI, also known as the Tei index, is a valid echocardiographic parameter due to its facility to assess general left ventricle performance. This index is less dependent on ventricular geometry and preload, is more sensitive than endocardial methods and transmitral Doppler flow imaging that are accessibly used to evaluate left ventricular function. It has been shown that MPI was correlated well with the left ventricular systolic and diastolic functions, which were measured invasively by cardiac catheterization.

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rial stiffness and LVMI. On the other hand, no difference was observed regarding arterial tension levels. Accordingly, one can argue that haemostatic tools such as baroreflex, neuroendocrine and renin-angiotensin associated mechanism may play a role in order to reduce the arterial pressure. Furthermore, recent results of a study by our institute, which evaluated the normotensive coarctated children who underwent intervention, demonstrated that levels of endothelin-1 were detected to be elevated in the patient group than healthy subjects, and it was proposed that high endothelin-1 level may play a role in the pathogenesis of late onset hypertension. 32

Limitations
This study had several limitations. First, the patient population incorporated in the current study were children with CoA receiving medical treatment related to common clinical issues encountered in clinical practice. However, we did not notice significant differences in terms of elasticity of the aorta and atrial ejection force between children who use and do not use medication. Another limitation of this study conceivably relates to the number of patients studied. Although this small sample size may represent a biased sample, we do not think that the patients included in this study had different clinical profiles than those who did not participate. The assessment of mitral are for the calculation of AEF may not be precise due to geometry of the mitral annulus. Manning’s method (our method for calculation of AEF) accepts a circular mitral annulus and takes no reflection of its form and area changes through the cardiac cycle. But, 3-dimensional echocardiographic techniques have granted new insights and comprehension of the saddle shape of the mitral annulus. 41,42 The importance of left atrial ejection force and elasticity of aorta in the pathophysiology of late hypertension for children with CoA are still unknown. Therefore, longitudinal studies with a larger number of patients that include adults are needed to clarify the effect of left atrium and vascular reactivity in the clinical course of CoA.

CONCLUSIONS
In the current study, we showed that the AEF is higher in children who have had successful coarctation surgery or balloon dilatation, and AEF is associated with systolic blood pressure, peak E velocity and LVMI. We also found that the distensibility of the ascending aorta was lower, and the stiffness index was higher in children with corrected CoA than in healthy subjects. The present study also revealed no association between age at repair or intervention and AEF index and aortic elastic properties. From these findings, we can suggest that augmented left AEF index and increased aortic stiffness may be used as markers for late hypertension in the follow up of CoA. Finally, further investigations with a larger number of patients and longer follow-up are merited to determine the role of these parameters in clinical practice.

CONFLICT OF INTEREST STATEMENT
On behalf of my co-authors, I declare that we have no financial, professional or other personal interest of any kind or sort in any product or company that could be interpreted as influencing the position presented in the manuscript entitled “Atrial functions and aortic elasticity in children with aortic coarctation”. We also affirm that this submission is with our knowledge and we are all familiar with the last version of manuscript.

REFERENCES
6. Maron BJ, Humphries JO, Rowe RD, Mellits ED. Prognosis of surgi-
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cally corrected coarctation of the aorta: a 20 year postoperative appraisal. 
9. Beekman RH, Katz BP, Moorehead-Steffens C. Altered baroreceptor function in children with systolic hypertension after 
10. Salgado HC, Skelton MM, Salgado MC, Cowley AW Jr. Physiopathogenesis of acute aortic coarctation hypertension in 
13. de Divitiis M, Pillia C, Kattenhorn M, et al. Ambulatory blood pressure, left ventricular mass, and conduit artery function later after 
Am Heart J 1982;103:879-86.
19. Franklin RCG, Wyse RKH, Graham TP, et al. Normal values for noninvasive estimation of left ventricular contractile state and 
Cardiol Young 2008;20:33-8.
38. Sehested J, Baandrup U, Mikkelsen E. Different reactivity and


