Left Ventricular Function in Children After Successful Repair of Aortic Coarctation

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Introduction and objectives. Lifetime prognosis following successful repair of aortic coarctation can be affected by a number of late complications. The objective of this study was to assess left ventricular function in these patients and to identify factors that predispose to functional abnormalities.

Methods. The study involved patients who had undergone repair of aortic coarctation and who had a pressure gradient ≤ 15 mm Hg after repair and normal systemic blood pressure. Echocardiographic data collected before repair and the results of the most recent postoperative left ventricular function studies were analyzed.

Results. The study involved 40 patients and 31 controls. Their mean age at repair was 6.9 years and the mean follow-up period was 4.25 years. During follow-up, the ejection fraction and the shortening fraction were observed to increase in 82.5% and 67.5% of patients, respectively. The myocardial performance index was abnormal in 47.5% of patients. The highest myocardial performance indices were observed in patients with arterial hypertension at diagnosis, in those who were aged over 4 years when they underwent repair, and in those with the most abnormal left ventricles before repair.

Conclusions. Measurement of the myocardial performance index showed that global left ventricular function was abnormal in 47.5% of patients after successful repair of aortic coarctation despite functional parameters being normal or elevated.

Key words: Left ventricle. Aortic coarctation. Left ventricular function. Myocardial performance index.
Abbreviations

AoCo: aortic coarctation
ET: ejection time
ICT: isovolumetric contraction time
IRT: isovolumetric relaxation time
LV: left ventricle
MPI: myocardial performance index

are alive at 40-50 years\(^1\)). This reduction in survival is due to complications such as recoarctation, hypertension, atherosclerotic disease, heart failure, early stroke, and even sudden death.\(^2\)\(^4\) The obstruction caused by AoCo causes pressure overload in the left ventricle (LV). After the obstruction has been resolved, LV adaptation to the original pressure overload may persist, even in patients with normal blood pressure and without a significant pressure gradient in the repair site, and abnormal remodeling has been described.\(^5\)\(^6\)

Using conventional endocardial indexes determined by echocardiography, previous studies have demonstrated normal or increased systolic performance in these patients.\(^7\)\(^8\) The myocardial performance index (MPI), or TEI-Doppler index, is an echocardiographic parameter that enables a more accurate assessment of overall LV performance.\(^9\) Its usefulness in the study of several heart diseases has already been demonstrated. The aim of this study was to evaluate overall LV performance using the MPI in children with a history of AoCo after successful repair and attempt to identify the factors that predispose toward persistent abnormalities and late complications.

Methods

Study Design

This observational study included patients with who had undergone successful repair of isolated AoCo by surgery or catheterization in our hospital from January 1990 to January 2007. Patients were included prospectively, but data were collected retrospectively. Repair was considered successful when the systolic blood pressure difference between the right arm and right leg was ≤15 mm Hg, confirmed by echocardiogram. The exclusion criteria included the following: patients with residual coarctation or recoarctation (systolic blood pressure difference between the right arm and right leg ≥15 mm Hg), hypertension (systolic blood pressure or diastolic blood pressure ≥90th percentile for age, sex and body surface area, or antihypertensive therapy), patients with some associated congenital heart disease (such as bicuspid aortic valve), some other complication associated with AoCo or its repair (aortic aneurysm, neurological sequelae, etc), systemic disease or clinical symptoms which could affect the assessment of LV function (sepsis, surgery, drugs, etc), and in cases where echocardiography was not performed prior to the repair or that was inappropriate for analysis. During the study period, 379 patients diagnosed with AoCo were treated in our hospital by surgery or catheterization: 285 (75%) had some associated congenital heart disease, including bicuspid aortic valve; 49 (52%) of the remaining 94 patients had some complication after AoCo repair (hypertension, recoarctation, residual coarctation, aneurysm in the AoCo site, neurological sequelae, etc). In 5 cases, the echocardiogram performed prior to AoCo repair was not suitable for analysis. The remaining 40 patients formed the study group (34 males). Age at the time of repair ranged from 10 days to 10 years (4.1 [3.2]; median, 3.8 [0.08-6.1] years). Age at the time of the study ranged from 43 days to 15 years (6.9 [2.1]; median, 5.2 [2.5-10.5] years). Follow-up time was between 1 month and 14.6 years (4.25 [2.9]; median, 4.1 [1.25-9.25] years). Surgical repair was performed in 27 (67.5%) patients. The surgical techniques employed were coarctectomy with end-to-end anastomosis in 23 (85%) patients, including 7 neonates, coarctectomy with left subclavian artery angioplasty in 3 (11%), and left subclavian artery angioplasty and teflon patch in 1. Transcatheter aortic angioplasty was performed in 13 (32.5%) using a Tyshak balloon in 11 and a Mansfield balloon in 2. Balloon diameters were 5-18 mm (10.1 [2.3]). The study included a control group of 31 healthy children referred to the hospital for vaccination or first visit for mild disorders such as caries, dermatitis, attention deficit, etc, in whom congenital heart disease or some other systemic disease had been ruled out. There were no differences between groups in age, sex, and body surface area. Patients were classified into 4 groups, according to clinical symptoms at the time of diagnosis as follows: a) asymptomatic and without arterial hypertension; b) with arterial hypertension; c) with heart failure; and d) in shock. The reason for consultation was heart failure in 13 (32.5%) patients; 12 asymptomatic patients were referred due to a murmur or a discrepancy between the femoral pulses, without hypertension being recorded at the time of diagnosis or during follow-up; 11 were referred due to arterial hypertension; and 4 neonates were admitted to the emergency department in a state of shock.

Echocardiographic Studies

The echocardiograms were analyzed prior to AoCo repair. The following were recorded: type of AoCo, gradient in the AoCo site, left ventricular ejection fraction...
(LVEF), left ventricular shortening fraction (LVSF), and LV mass and volume at LV end-diastole. The values of LV mass and volume at LV end-diastole of the patients were compared to normal values for age, weight, and body surface area, and used to classify them into 4 groups:

1. Mild-to-moderate LV hypertrophy without dilatation: LV mass ≤±3 standard deviations of the normal LV value and volume at end-diastole ≤±1 standard deviation of the normal value.
2. LV hypertrophy and mild-to-moderate dilatation: LV mass >+3 standard deviations of the normal LV value and volume at end-diastole >+3 standard deviations of the normal value.
3. Severe LV hypertrophy with or without dilatation: LV mass ≥±3 standard deviations of the normal LV value and volume at end-diastole ≤±3 standard deviations of the normal value.
4. Severe LV dilatation with or without hypertrophy: LV mass ≤±3 standard deviations of the normal LV value and volume at end-diastole >+3 standard deviations of the normal value.

To evaluate current LV performance, a Sonos 5500 Philips echocardiograph was used with simultaneous electrocardiographic tracing. The measurements were obtained with an average of 5 consecutive cycles. The corrected residual gradient in the AoCo site was obtained in the suprasternal view using the Bernoulli equation. The LVEF and LVSF were obtained in the parasternal long-axis view in M mode following standard methodology. Left ventricular mass was calculated using the Dereveux formula adjusted to the body surface area. The MPI was obtained in the apical 5-chamber view using the following formula:

\[ \text{MPI} = \text{ICT} + \frac{\text{IRT}}{\text{ET}} \]

where the isovolumetric contraction time (ICT) is the interval between the end of mitral flow and the beginning of aortic flow; the isovolumetric relaxation time (IRT) is the interval between the end of aortic flow and the beginning of the following mitral flow; and ejection time (ET) is the interval from the beginning of aortic flow until the end. The MPI was considered normal if it was ≤0.42.

**RESULTS**

There was localized juxta ductual AoCo in 29 (72.5%) patients and 11 patients had AoCo associated with a certain degree of hypoplasia of the aortic isthmus or the transverse aortic arch. The pressure gradient in the AoCo site was 45 mm Hg. The LVEF and LVSF were normal in all the patients at the time of diagnosis. Before the repair, 20 (50%) patients had a pattern of moderate hypertrophy, with a slight degree of ventricular dilatation; 15 (37.5%) patients had moderate left ventricular hypertrophy only without dilatation; and 5 patients were of special note due to the special characteristics of the LV. Three had severe LV dilatation, with a slight degree of LV hypertrophy, and 2 had severe LV hypertrophy, given the normal course of the disease. Table 1 shows the baseline clinical and echocardiographic characteristics of the patients before AoCo repair.

### Evaluation of the Left Ventricle After Successful Repair of Aortic Coarctation

Table 2 shows the results of successful AoCo repair on LV function. The LVEF increased in 33 patients, was normal in 6, and decreased in 1 patient who underwent intervention at 8 years of age, and who had severe hypertension and concentric left ventricular hypertrophy at the time of diagnosis. The LVSF increased in 27 patients and was normal in 13. Both the LVEF and LVSF were significantly higher in the patient group than in the control group (LVEF: 79 [5.88] vs 68.14 [3.49], \( P = .028 \); and LVSF: 44 [4.11] vs 37.8 [6.5], \( P = .031 \) (Figure 1). The ICT was 0.051 s; IRT, 0.058 s; and ET, 0.259 s. The ICT was significantly greater in the patient group (0.051 vs 0.036; \( P = .018 \)). This was also the case for the IRT (0.058 vs 0.026; \( P = .011 \)) and MPI (0.45 vs 0.34; \( P \leq .029 \)). On the other hand, the ET was significantly less in the patient group (0.259 vs 0.34; \( P = .029 \) (Figures 2 and 3). Nineteen patients (47.5%) had an abnormal MPI (>0.42) and in 21 patients (52.5%) MPI was normal (≤0.42).

The univariate analysis showed a statistically significant association between abnormal MPI and age >4 years at the time of repair, arterial hypertension at the time of diagnosis, and the LV having abnormal echocardiographic characteristics before repair, since the patients older than ...
At the time of repair, those with hypertension ($P=.026$), and those with a very dilated LV ($P=.042$) or severely hypertrophic LV ($P=.045$) at the time of diagnosis had a significantly greater MPI (Table 3). Multivariate logistic regression analysis, which included the variables associated with ventricular function, showed that factors associated with a greater MPI were male sex ($P=.028$), age at repair ($P=.031$), presentation with heart failure ($P=.018$), type of aortic coarctation ($P=.011$), LVEF ($P=.041$), and LVSF ($P=.029$). These findings highlight the importance of considering individual patient characteristics in the management of aortic coarctation.

**Figure 1.** Comparison of left ventricular ejection fraction (LVEF) and left ventricular shortening fraction (LVSF) in children after aortic coarctation (AoCo) repair and healthy children.

**Figure 2.** Comparison of isovolumetric contraction time (ICT), isovolumetric relaxation time (IRT), and ejection time (ET) in children after aortic coarctation (AoCo) repair and healthy children.
dysfunction in the univariate analysis, age >4 years at the time of repair, severe LV hypertrophy or dilatation before the repair and increased left ventricular mass, had an odds ratio (OR) >1. However, only hypertension was shown to be an independent risk factor predicting left ventricular dysfunction in this patient group (Table 4). There were no significant differences between groups regarding sex, type of coarctation, and the treatment modality for AoCo.

**DISCUSSION**

Due to the high rate of late complications, some studies point out that AoCo, rather than being an isolated entity characterized by the simple mechanical obstruction of the aorta, is actually a general disease of the cardiovascular system. The following factors have been proposed as predisposing to persistent abnormalities: older age at the time of repair,2,3 impaired elastic properties of the aorta,12,13 different thresholds of the autonomic nervous system,14,15 and hypertension3 and persistent LV hypertrophy. After the obstruction caused by AoCo has been eliminated, the LV begins a remodeling process; however, the LV geometry and hypertrophy do not completely return to normal5: abnormal patterns of remodeling with concentric hypertrophy have been verified in 12.5% of patients and eccentric remodeling in up to 27.5%.6 Previous studies conducted with conventional echocardiographic methods have demonstrated that LV systolic function and contractility increase in patients after AoCo repair.7,8 These studies contrast with animal models where pressure overload was induced16,17 and with studies in humans with hypertension18,19 where LV hypertrophy would not regress.

**TABLE 3.** Left Ventricular Function in Healthy Children and in Patients After Successful Repair of Aortic Coarctation According to Age at the Time of Repair

<table>
<thead>
<tr>
<th>Variable</th>
<th>Healthy Children (n=31)</th>
<th>AoCo Repair Before 4 y (n=23)</th>
<th>AoCo Repair After 4 y (n=17)</th>
<th>P (Healthy/ &lt;4 y)</th>
<th>P (Healthy/ &gt;4 y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVEF, %</td>
<td>68.14 (3.49)</td>
<td>80.7 (7.12)</td>
<td>79.5 (8.35)</td>
<td>.026</td>
<td>.029</td>
</tr>
<tr>
<td>LVSF, %</td>
<td>37.85 (6.53)</td>
<td>41.87 (8.72)</td>
<td>42.27 (7.8)</td>
<td>.030</td>
<td>.025</td>
</tr>
<tr>
<td>ICT, s</td>
<td>0.036 (0.002)</td>
<td>0.048 (0.013)</td>
<td>0.054 (0.015)</td>
<td>.050</td>
<td>.011</td>
</tr>
<tr>
<td>IRT, s</td>
<td>0.026 (0.005)</td>
<td>0.055 (0.013)</td>
<td>0.061 (0.016)</td>
<td>.006</td>
<td>.005</td>
</tr>
<tr>
<td>ET, s</td>
<td>0.340 (0.040)</td>
<td>0.270 (0.023)</td>
<td>0.246 (0.030)</td>
<td>.049</td>
<td>.019</td>
</tr>
<tr>
<td>MPI</td>
<td>0.34 (0.05)</td>
<td>0.40 (0.09)</td>
<td>0.50 (0.014)</td>
<td>.045</td>
<td>.015</td>
</tr>
</tbody>
</table>

AoCo indicates aortic coarctation; ICT, isovolumetric contraction time; IRT, isovolumetric relaxation time; LV, left ventricle; LVEF, left ventricular ejection fraction; LVSF, left ventricular shortening fraction; MPI, myocardial performance index.

Values are expressed as mean (standard deviation).
was associated with a gradual deterioration in ventricular function and contractility. In altered LV geometry, fiber shortening is nonuniform, since subendocardial myocardial fiber shortening exceeds subepicardial shortening, and thus the endocardial indices frequently overestimate fiber shortening. Some authors have proposed that normal or elevated LVEF and LVSF imply systolic dysfunction in the presence of LV hypertrophy. The MPI is an echocardiographic parameter that includes ICT, IRT, and ET in its calculation, making it possible to evaluate overall LV performance. Given that this approach is less dependent on ventricular geometry and preload, it is much more sensitive than the endocardial methods and Doppler flow imaging of the mitral valve that are traditionally used to evaluate ventricular function. These findings agree with recent studies that have demonstrated abnormal regional myocardial deformation properties with reduced LV longitudinal shortening and increased LV circumferential shortening in patients after successful AoCo repair.

We found that being aged >4 years at the time of repair and an LV with very abnormal characteristics before the repair could be involved in the general LV dysfunction observed in our patients, although only arterial hypertension before repair proved to be an independent risk factor for general dysfunction evaluated with the MPI (Tables 4 and 5). The findings of this study are clinically relevant, since the subtle and subclinical abnormalities in LV function associated with a rigid aorta with little elasticity, an abnormal pulse wave at the repair site, and the previously described abnormalities of the autonomic system can play a role in the appearance of late arterial hypertension in a high percentage of cases after AoCo repair which, in turn, predispose to greater LV

### TABLE 4. Univariate Analysis. Relationship of Clinical and Echocardiographic Factors to Left Ventricular Dysfunction Evaluated by Myocardial Performance Index

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal MPI (n=21)</th>
<th>Abnormal MPI (n=19)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>19 (90.47)</td>
<td>15 (78.94)</td>
<td>.639</td>
</tr>
<tr>
<td>Age at time of repair, mean (SD), y</td>
<td>3.5 (3.07)</td>
<td>4.29 (3.5)</td>
<td>.330</td>
</tr>
<tr>
<td>Course, mean (SD), y</td>
<td>3.66 (3.9)</td>
<td>5.05 (4.1)</td>
<td>.276</td>
</tr>
<tr>
<td>Presentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart failure</td>
<td>9 (42.85)</td>
<td>4 (21)</td>
<td>.059</td>
</tr>
<tr>
<td>Asymptomatic</td>
<td>8 (38.09)</td>
<td>4 (21)</td>
<td>.062</td>
</tr>
<tr>
<td>Hypertension</td>
<td>2 (9.52)</td>
<td>9 (47.5)</td>
<td>.026</td>
</tr>
<tr>
<td>Shock</td>
<td>2 (9.52)</td>
<td>2 (10.5)</td>
<td>.299</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgical repair</td>
<td>15 (71.4)</td>
<td>12 (63.15)</td>
<td>.379</td>
</tr>
<tr>
<td>Angioplasty</td>
<td>6 (28.6)</td>
<td>7 (15.8)</td>
<td>.381</td>
</tr>
<tr>
<td>Type of AoCo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Localized juxtaductal</td>
<td>16 (76.2)</td>
<td>13 (68.4)</td>
<td>.286</td>
</tr>
<tr>
<td>Associated with hypoplastic aortic arch</td>
<td>5 (23.8)</td>
<td>6 (31.6)</td>
<td>.491</td>
</tr>
<tr>
<td>LV characteristics before repair</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate hypertrophy</td>
<td>11 (52.38)</td>
<td>4 (21.05)</td>
<td>.219</td>
</tr>
<tr>
<td>Moderate hypertrophy and dilatation</td>
<td>10 (47.62)</td>
<td>10 (52.63)</td>
<td>.298</td>
</tr>
<tr>
<td>Severe dilatation with or without hypertrophy</td>
<td>0</td>
<td>3 (15.78)</td>
<td>.042</td>
</tr>
<tr>
<td>Severe hypertrophy with or without dilatation</td>
<td>0</td>
<td>2 (10.52)</td>
<td>.045</td>
</tr>
</tbody>
</table>

AoCo indicates aortic coarctation; LV, left ventricle; MPI, myocardial performance index. Values are expressed as mean (standard deviation) or number (percentage).
Study Limitations

The present study has several limitations. The most important is follow-up time, which was not homogeneous among the patients and was sometimes very short. The second limitation is that blood pressure and the gradient in the coarctation site were not measured during exercise, as well as following up overall LV performance to carefully assess indications for beta-blockers or angiotensin-converting enzyme inhibitors.

CONCLUSIONS

The overall LV performance evaluated with the MPI was abnormal in 47.5% of cases of AoCo even after successful repair and despite having normal or increased endocardial indices. It is likely that arterial hypertension before repair, older age at the time of repair and evidence of very abnormal LV at the time of diagnosis can play a role in suboptimal LV remodeling. However, the sample size makes it impossible to identify the independent factors that lead to ventricular dysfunction developing in these patients. Longitudinal studies including a greater number of cases and longer follow-up time are needed to attempt to determine the mechanisms that explain the persistent abnormalities in these patients.

REFERENCES


