Haemodynamic and echocardiographic findings after aortoventriculoplasty*


Department of Paediatric Cardiology and *Thoracic and Cardiovascular Surgery, Georg-August-University, Göttingen, F.R.G.

KEY WORDS: Aortoventriculoplasty, left ventricular outflow tract obstructions, postoperative haemodynamic and echocardiographic studies.

Aortoventriculoplasty (AVP) is an established operative procedure for the enlargement of different types of severe left ventricular outflow tract obstruction. Between 1974 and 1985 75 aortoventriculoplasties were carried out in 72 patients ranging from 5 to 34 years of age. Three patients had to be reoperated upon due to significant right ventricular outflow tract obstruction, outgrown prosthesis, and dissecting aortic aneurysm. There were 7 early deaths (mortality rate 9.3%) and one late death (1.3%) following AVP. Out of the last 55 patients only 2 died (3.6%). In contrast to the unsatisfactory haemodynamic results of previous conventional operations, AVP reduced the mean residual gradient at rest across the left ventricular outflow tract from 84 ± 23 mmHg (range 50–160 mmHg) to 12 ± 12 mmHg (range 0–65 mmHg). Except in 2 patients, no gradient increased more than 15 mmHg with isoproterenol.

In the cross-sectional echocardiogram, the left ventricular outflow tract was enlarged from 1.9 ± 0.42 to 3.1 ± 0.39 cm after AVP, whereas the aortic annulus had been expanded from 2.4 ± 0.36 to 3.2 ± 0.35 cm (n = 17). The mean length of the inner patch covering the septal incision measured 2.1 cm ± 0.4 cm (n = 37).

Our recatheterization studies after AVP revealed equally good haemodynamic results in all types of left ventricular outflow tract obstruction which cannot be relieved by conventional surgery.

The conventional operative treatment of certain severe forms of congenital stenosis of the left ventricular outflow tract remains problematic because of their complex and unfavourable pathology[14–21]. In particular, the tunnel-shaped subaortic stenosis, which is often associated with a narrow hypoplastic annulus, is resistant to this procedure and poses an insoluble problem for the cardiac surgeon[6–9]. For this 'problem group' of patients, therefore, new operative procedures have been developed in the last few years with rather promising results[44,9–12].

Aortoventriculoplasty, described by Rastan and Koncz[11,13], was first undertaken in 1974 in a 12-year-old patient with a Shone complex and tunnel subaortic stenosis. Konno[9] independently used a similar technique in 1975 for congenital aortic stenosis associated with hypoplasia of the aortic valve ring. This surgical procedure consists of enlarging the left ventricular outflow tract by longitudinal aortotomy, opening the right ventricle just beneath the pulmonary valve, dividing the aortic ring midway between the right and left coronary ostia and extending the incision into the interventricular septum. The aortic valve is resected and replaced by a prosthetic valve. The septal and aortic incisions are roofed by a rhomboid prosthetic patch and the right ventricular outflow tract is reconstructed by a second triangular patch plasty. Since 1974 the indication for this operative technique has been extended to other types of left ventricular outflow tract stenoses. The purpose of our study was a check of the haemodynamic results achieved by this new surgical procedure. So far, 41 of 72 patients with aortoventriculoplasty have been recatheterized.

Patients and methods

From 1961 to 1985, 1265 children with various types of congenital aortic stenosis were diagnosed in the Department of Paediatric Cardiology in Göttingen; 547 of these patients underwent conventional surgery: 303 patients with valvular, 59...
with supravalvular and 185 with subvalvular aortic stenosis. Since 1974, 72 patients have undergone 75 aortoventriculoplasties. This operation was selected as the first surgical intervention in only 11 patients while 48 patients had one and another 13 patients had two preceding conventional operations. The mean age at operation was 15.3 years (range 5 to 34 years).

Aortoventriculoplasty was indicated in different types of congenital aortic stenosis as follows (Table 1): (1) valvular aortic stenosis with narrow annulus

Table 1 Pathology in 72 patients operated on with aortoventriculoplasty, 1974–1985

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Operations</th>
<th>Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valvular aortic stenosis, with narrow annulus</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Diffuse SAS tunnel like 16 (with Shone complex ?)</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>Multilevel stenosis</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td>Outgrown aortic prosthesis</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>HOCM-Reoperation</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td>8</td>
</tr>
</tbody>
</table>

SAS — subaortic stenosis
HOCM — hypertrophic obstructive cardiomyopathy.

(n=16); (2) diffuse subaortic stenosis (n=26 — including 7 with the Shone complex); (3) multilevel stenosis (n=22); (4) outgrown prosthesis (n=7); (5) HOCM-reoperation (n=4). Of the 72 patients who underwent AVP 8 died, resulting in a total mortality of 11.1%. There were 7 hospital deaths and 1 late death due to rhythm disturbances. Out of our last 55 patients, only 2 died (mortality rate 3.6%). The causes of death were myocardial failure (3 patients), pulmonary insufficiency with pulmonary hypertension (2 patients), renal failure and myocardial infarction in one case of coronary anomaly. Up to June 1985, 41 patients were re-examined, 1 patient twice. Complete right and left cardiac recatheterization was performed at a mean interval of 18.7 months (range 1 month to 51 years) following AVP. The left heart was catheterized after transseptal puncture except in one patient with a Björk–Shiley disc valve in the mitral position and in 3 other cases. This was followed by percutaneous retrograde catheterization of the ascending aorta. A third catheter was inserted percutaneously into the pulmonary artery in order to measure cardiac output at rest and under drug therapy (cardiogreen injections and thermodilution). The pressures in the left ventricle and the ascending aorta were recorded simultaneously at rest and under drug treatment (isoproterenol 0.1 μg kg⁻¹ body weight). Left ventricular angiography was performed in all cases in which the left ventricle could be catheterized.

The echocardiographic studies were performed with a cross sectional phased array sector scanner. All patients were examined in the supine or oblique position via the third or fourth intercostal space parasternally with a 2.5 or 3.0 MHz transducer. Using a display cursor to select the desired radial direction from the sector image, appropriate measurements were made from a M-mode recording which was derived from the sector scan. A complete pre- and postoperative examination of the aorta, left ventricular outflow tract and left

Figure 1 Left ventricular-aortic gradients before and after conventional operative procedures.
Haemodynamic and echocardiographic findings after aortoventriculoplasty

Ventricular cavity was so far accomplished in 17 patients after AVP. We measured (1) the internal aortic diameter in diastole in the region of the aortic annulus (AO-D) and (2) the smallest left ventricular outflow tract dimension (LVOT) within the selected sweep (C-point of the base of the anterior mitral leaflet to the left septal surface). We also used the LVOT: AO-D ratio to evaluate the severity of the LVOT narrowing. In patients with left ventricular outflow tract obstruction associated with narrow annulus the ratios were rejected. To assess the length (distance: aortic annulus-septum) of the inner dacron patch covering the septal incision, measurements were taken from the two-dimensional pictures of the longitudinal cross sections of the heart. The echocardiographic measurements are expressed as mean ± SD. The paired t-test used to check the changes in gradient after previous conventional surgery and after AVP was considered significant at $P < 0.05$.

Catheterization studies

The individual changes in the gradient across the left ventricular outflow tract before and after earlier conventional operative procedures are shown in Fig. 1. The previously measured gradients could be compared with the postoperative values in 39 patients. It appears, that the gradient could be lowered in some of the patients by conventional operations. However, all patients in this group except one had a residual left ventricular-aortic gradient of at least 50 mmHg or more. The mean gradient at rest decreased only from $99 ± 24$ mmHg to $85 ± 30$ mmHg.

Forty-one of the 64 surviving patients have been restudied at a mean postoperative interval of 18-7 months (range 1 month to 5½ years) following AVP. In 4 patients the left ventricle could not be catheterized. Figure 2 shows a comparison of the measured pressure gradients before and after AVP in 37 patients obtained at a mean interval of 4-5 years (range 1 to 14 years) after the last conventional operation. It can be recognized that subsequent AVP resulted in a significant lowering of the mean residual gradient at rest from $84 ± 23$ to $12 ± 12$ mmHg in all patients but one, in whom a gradient of 65 mmHg persisted. This patient had undergone replacement of an originally small aortic valve prosthesis (21 mm) which he had outgrown. In this child a second AVP was performed and the outgrown prosthesis was replaced.

Figure 2 Individual changes of left ventricular-aortic gradients in 37 patients after aortoventriculoplasty (AVP).

Figure 3 Individual changes of left ventricular enddiastolic pressure (LVEDP) before (preop.) and after (postop.) aortoventriculoplasty. The preoperative data are plotted against the postoperative ones (1 = identity).
after 6 years by a 25 mm Björk–Shiley valve. Recatheterization revealed a relatively high gradient of 40 mmHg which, in our opinion, is due to an oblique position of the artificial valve in the left ventricular outflow tract. With this one exception, all postoperative pressure gradients were normalized if the natural gradient across the valve prosthesis of up to 25 mmHg is taken into consideration (Fig. 2 dotted line). The cardiac index at rest had a mean value of $3.8 \pm 1.21 \text{ml} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ and rose approximately 18% with isoproterenol. This moderate drug stress led to an increase in pressure gradient of no more than 15 mmHg, except in 2 patients in whom it rose to 35 mmHg. There was no increase in 13 patients. Figure 3 shows the individual changes of left ventricular end-diastolic pressures when preoperative are plotted against postoperative data. The identity line is marked by 1. Analysis of these findings shows that among 33 patients, left ventricular end-diastolic pressure (LVEDP) remained within the normal range (left lower quadrant) in 15, while in 9 others it could be reduced (right lower quadrant). In 3 patients postoperative LVEDP was above the normal range in comparison to preoperative values (left upper quadrant). In 6 patients the LVEDP remained pathological and unchanged after AVP (right upper quadrant). It can, therefore, be concluded that AVP caused no significant change in about 50% of the patients, whereas the LVEDP returned to normal in 25%.

In 3 patients, recatheterization and angiography revealed a small ventricular septal defect within the patch-covered septal incision. Another 7 patients had gradients across the right ventricular outflow tract resulting from too narrow a right ventricular outflow patch, but the pressure gradient was significant at 40 mmHg in only one patient. Mild aortic regurgitation due to the prosthetic valve or a paravalvular aortic leak was found in another 6 patients. Three patients had to be reoperated upon due to right ventricular outflow tract obstruction, outgrown prosthesis, and a dissecting aneurysm of the ascending aorta which occurred in one patient six months after AVP as the result of a suture dehiscence.

For our entire group of 72 patients, survival and adverse event-free curves were calculated by the methods of Kaplan and Meier. Figure 4 shows that 86% of the patients have the prospect of being alive 10 years after aortoventriculoplasty. Cumulative postoperative event analysis portends a less favourable outlook. We considered adverse events postoperatively to include permanent complete AV-block, reoperation, or death. The event-free analysis of our series predicts that the likelihood of a patient surviving without an adverse event is 76% at 10 years.

<table>
<thead>
<tr>
<th>ECG-changes after aortoventriculoplasty (n = 72)</th>
<th>Preop.</th>
<th>Postop.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinus rhythm</td>
<td>72</td>
<td>69</td>
</tr>
<tr>
<td>Complete AV-block</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Complete RBBB</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>LAH</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Complete RBBB and LAH</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

AV — atrioventricular, RBBB — right bundle branch block, LAH — left anterior hemiblock.
The ECG changes before and after AVP are listed in Table 2. Three patients needed a transvenous pacemaker implantation due to permanent AV-block. Complete right bundle branch block (RBBB) was observed in 16 patients after AVP which, however, had already been present before the operation in 6 cases. A left anterior hemiblock (LAH) was found in another 7 patients, and the combination of a complete RBBB with LAH appeared after the operation in 10 patients.

The preoperative and postoperative left ventricular angiograms in a 9-year-old male with tunnel subaortic stenosis are shown in Figure 5. In this patient AVP was performed as a first surgical intervention. Postoperatively, the outflow tract seen in the transseptal left ventricular angiogram is sufficiently widened. There was no residual gradient.

In the last few years, cross-sectional echocardiography has proved to be a valuable tool in the assessment and discrimination between the different types of obstruction in the left ventricular outflow tract [15,16]. In contrast to angiography, normal values for the aortic root and left ventricular outflow tract in reference to body weight are available [17]. Figure 6 (a) shows a cross-sectional echo in the long axis of the heart of a patient with valvular aortic stenosis and subvalvular obstruction caused by an abnormally thickened interventricular septum. The black arrows indicate the anterior and posterior wall of the aorta and the poststenotic dilatation. The narrow hypoplastic annulus can be

**Table 3 Echocardiographic measurements before and after aortoventriculoplasty**

<table>
<thead>
<tr>
<th></th>
<th>Preop.</th>
<th>Postop.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVOT</td>
<td>1.9 ± 0.42 cm</td>
<td>3.1 ± 0.39 cm</td>
</tr>
<tr>
<td>Ao-D</td>
<td>2.4 ± 0.36 cm</td>
<td>3.2 ± 0.35 cm</td>
</tr>
<tr>
<td>LVOT/Ao-D (n=13; pts with narrow annulus excluded)</td>
<td>0.65 ± 0.22 cm</td>
<td>1.03 ± 0.07 cm</td>
</tr>
<tr>
<td>Length: inner dacron patch (LVOT, n=37)</td>
<td>2.1 ± 0.4 cm</td>
<td></td>
</tr>
</tbody>
</table>

LVOT—left ventricular outflow tract, Ao-D—diastolic aortic diameter at annulus. Values are expressed as mean ± SD.
Figure 6(a)  Long axis. Cross-sectional echocardiogram in a 20-year-old male with narrow aortic annulus and subvalvular obstruction caused by a thickened interventricular septum (AWAO, PWAO = anterior and posterior aortic wall; AOV = aortic valve; AML, PML = anterior and posterior mitral leaflet; IVS = interventricular septum; RVOT = right ventricular outflow tract).

Figure 6(b)  Same patient as in Fig. 5(a). Long axis—the aortic annulus and the left ventricular outflow tract are distinctly widened after AVP (LA, LV = left atrium, left ventricle; MV = mitral valve; SJM = Saint Jude Medical prosthesis).
clearly recognized: the thickened aortic cusps are in early diastolic position. After AVP [Fig. 6 (b)] the outflow tract and the aortic annulus are distinctly widened. In the long-axis scan of the heart there is direct and clear visualization of the inner dacron patch and its length (marked by a P). The implanted St Jude Medical prosthesis produces dense echoes.

The echocardiographic measurements given in mean values and their standard deviations are listed in Table 3. Pre- and postoperative echocardiograms could be compared in 17 patients. In the cross-sectional echocardiogram, the left ventricular outflow tract was enlarged on average from 1.9 ± 0.42 to 3.1 ± 0.39 cm after AVP, whereas the aortic annulus had been expanded from 2.4 ± 0.36 to 3.2 ± 0.35 cm. In patients with diffuse subaortic stenosis (excluding patients with an additional narrow annulus) the ratio LVOT/aortic annulus was 0.65 ± 0.22 before and 1.03 ± 0.07 cm after AVP. The length of the inner dacron patch covering the septal incision could be directly visualized in 37 patients and measured 2.1 ± 0.4 cm.

**Discussion**

The haemodynamic results obtained by AVP as a special method for widening the narrow outflow tract of the left ventricle have been rather promising during a 10-year follow-up [18-21]. Apart from Konno [22], several authors have since reported this successful use of aortoventriculoplasty [23, 24]. In comparison with other newly developed procedures (resection of narrow aortic annulus and homograft implantation, use of extracardiac valved ventricular aortic conduit, dorsal annuloplasty) aortoventriculoplasty is applicable in all types of left ventricular outflow tract obstructions. It may be an additional help for the various types of left ventricular outflow tract obstructions. It could not be relieved by conventional surgery. Cross-sectional echocardiography is useful in evaluating the size of the aortic annulus as well as the various types of left ventricular outflow tract obstructions. It is an additional help for the preoperative assessment of the indication for AVP. We recommend the use of AVP in patients older than 4 years when stringently indicated after excluding other alternatives for the 'problem group' of patients with a narrow left ventricular outflow tract.

**References**


**Haemodynamic and echocardiographic findings after aortoventriculoplasty**

507


