Aortoventriculoplasty for Tunnel Subaortic Stenosis and Other Obstructions of the Left Ventricular Outflow Tract

Clinical and Hemodynamic Results

PER G. BJÖRNSTAD, M.D., HOUSCHANG RASTAN, M.D., JÜRGEN KEUTEL, M.D., ALOIS J. BEUREN, M.D., AND JOSEF KONCZ, M.D.

SUMMARY  A new therapeutic concept of enlarging the outflow tracts of both ventricles with a patch and inserting an aortic prosthesis has been developed for the treatment of tunnel subaortic stenosis. This operation has been applied clinically since June 1974 on several types of obstruction in the outflow tract of the left ventricle.

Twenty-one operations have been performed on 20 patients under the age of 18 years, with an overall mortality of 24% and no late deaths. Seven patients developed complete right bundle branch block or left anterior hemiblock or both as a result of this operation; transient atrioventricular block and complete left bundle branch block occurred in one patient each. In no case, however, did rhythm disturbances contribute to death. In one patient, the septal incision injured a septal coronary artery, with fatal result.

Fourteen patients had catheterization studies postoperatively. Although previous conventional surgery had been unsuccessful, aortoventriculoplasty (AoVPI) reduced the mean gradient across the left ventricular outflow tract significantly \( p < 0.01 \), from \( 94.7 \pm 25.5 \text{ mm Hg} \) to \( 14.4 \pm 17.2 \text{ mm Hg} \), leaving the end-diastolic pressure practically unchanged. No significant defect remained in the patch-covered septal incision.

Thus, we consider AoVPI to be the operation of choice for tunnel subaortic stenosis, for valvular aortic stenosis with a narrow annulus and in cases where an artificial aortic valve has become too small because of the patient's growth.

THE RESULTS of conventional operations for tunnel subaortic stenosis have been disappointing.\(^1\) Sarnoff et al.\(^2\) reported their results on the use of a valved anastomosis between the apex of the left ventricle and the aorta in dogs, and operations of this kind have been performed recently in man.\(^3\)\(^-\)\(^7\)

The method reported here consists in enlarging the left and right ventricular outflow tracts by means of a patch and inserting an aortic valve prosthesis. After our first reports,\(^6\)\(^,\)\(^8\) we learned that Konno et al.\(^9\) had independently developed a similar procedure; Symbas et al.\(^11\) also reported a case operated in this manner.

In this article we present the first clinical and hemodynamic results of this operation in the pediatric and adolescent age groups.

Materials and Methods

Surgical Technique

After cardioplegia is induced, a transverse incision is made across the right ventricular outflow tract, \( 1-1.5 \text{ cm} \) below the pulmonary valve ring (fig. 1A). Then, a longitudinal aortotomy is continued to within a few millimeters of the left side of the right coronary ostium. Next, the aortic and right ventricular incisions are joined together over the aortic valve ring (fig. 1B).

The aortic incision is continued through the thickened interventricular septum in the region of the crista supraventricularis until it extends beyond the stenosis. Thus, it is possible to make a septotomy almost to the apex of the heart, although this has never been necessary.

The septal incision is reconstructed by an "inner" dacron patch (fig. 1C). The aortic valve that has been removed is replaced by a Björk-Shiley disc valve prosthesis (fig. 1D), which is sutured to the aortic ring and to the patch with continuous sutures. The aortic incision is covered by the same patch, which can enlarge the aortic root circumference almost twofold.

Finally, the right ventricular gap is closed by a second, triangular, "outer" patch (fig. 1E), which is sutured to the aortic patch after the aortic clamp has been removed. Figure 1F shows the completed aortoventriculoplasty (AoVPI).

The mean perfusion time of survivors was 91 ± 26 minutes (range 48–143 minutes). The mean cardiac arrest time was 57 ± 12 minutes (range 36–78 minutes). These times did not differ significantly in the nonsurvivors, except for one case mentioned below.

The size of the prosthesis inserted has varied, but it tends to be larger now than it was at first. For the last 10 operations no valve smaller than #25 has been used.

Clinical Material

AoVPI has been performed on 20 patients under the age of 18 years since June 1974 (fig. 2). One patient
was operated twice. There were 14 male patients and six females. The mean age at operation was 11.4 ± 2.8 years. The youngest patient was 5 years old. AoVPl was the second operation on the left ventricle for 10 patients, and the third for three patients. In one patient a pulmonary stenosis had been operated upon, another had had a patent ductus closed previously, and six patients had not had previous cardiac surgery.

The major lesion (table 1) in nine patients was a tunnel subaortic stenosis. A valvular stenosis with a narrow ring was present in five cases, and in three cases an aortic prosthesis inserted in earlier childhood had to be replaced due to the patient's growth. Two patients had Shone's complex. In one case a second AoVPl was performed after 4 weeks because of bacterial endocarditis. This patient also had a small ventricular septal defect and a paravalvular leak. At the repeat operation, a smooth neointima was observed covering the aortoseptal patch.

The mean preoperative gradient was 94.7 ± 25.9 mm Hg (range 60-150 mm Hg). Earlier operations performed in the conventional manner on seven patients had been disappointing, merely reducing the mean gradient insignificantly (p < 0.05) from 104.0 ± 21.3 mm Hg to 93.2 ± 24.7 mm Hg (fig. 3).

Additional cardiac anomalies were present in 12 cases. Three patients had aortic insufficiency and two others had a ventricular septal defect with additional aortic insufficiency. Three patients had mitral insufficiency, one of them with a tricuspid mitral valve. One patient had a valvular pulmonary stenosis, another had an incomplete atrioventricular canal without ventricular septal defect, left ventricular conus and kinking of the aorta. Two patients had mild coarctation. Two others had a patent ductus and an aberrant right subclavian artery. Three patients had Noonan's syndrome.

Table 1. Primary Lesion in 20 Pediatric Patients Operated with Aortoventriculoplasty

<table>
<thead>
<tr>
<th>Lesion</th>
<th>n</th>
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<tbody>
<tr>
<td>Tunnel subaortic stenosis</td>
<td>9</td>
</tr>
<tr>
<td>Valvular aortic stenosis</td>
<td>5</td>
</tr>
<tr>
<td>Shone complex</td>
<td>2</td>
</tr>
<tr>
<td>VSD and aortic insufficiency operated</td>
<td>3</td>
</tr>
<tr>
<td>previously with valve replacement</td>
<td></td>
</tr>
<tr>
<td>Idiopathic hypertrophic subaortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
</tr>
</tbody>
</table>

Abbreviation: VSD = ventricular septal defect.
Mortality

All survivors were examined at a mean postoperative interval of 0.6 years after operation. One patient refused catheterization.

Methods of Restudy

All 15 survivors were studied clinically with the ECG, x-ray, phonocardiography and pulse tracings, and single-beam echocardiography. Echocardiographic examinations were performed on nonmedicated patients using a Smith Kline Ekoline 20 A with a 2.25 MHz transducer focused at 5 cm and with a repetition rate of 1000/sec. Strip chart recording was done with a Honeywell 1856 fiberoptic recorder. One patient refused catheter study. Fourteen patients were studied by right- and left-heart catheterization. The left ventricle was catheterized after transseptal puncture of the left atrium, except in the patient with a Björk-Shiley disc valve in the mitral position. The ascending aorta was catheterized by percutaneous retrograde catheterization. Pressure tracings were recorded with fluid-filled catheters by a Statham P23Db transducer on an Electronics for Medicine recorder. The pressures in the left ventricle and aorta were registered simultaneously at rest and under drug stress: Isoproterenol 0.01 μg/kg body weight was injected over 30 seconds into the ascending aorta and pressures were registered at maximum heart rate. Corresponding cardiac output at rest and under isoproterenol was determined by cardiogreen injections. Left ventricular angiography was performed in all cases where the left ventricle could be catheterized; in some cases, right ventricular angiography was also done. An aortogram was performed in all cases of suspected aortic insufficiency. In some cases, cineangiography was used for the left ventricle, in most cases, however, cut films were used.

Statistical Methods

We compared the reduction of gradient after conventional surgery vs AoVPI using the Wilcoxon test,
considered significant at \( p < 0.01 \). We tested the change in gradient after previous conventional surgery and in left ventricular end-diastolic pressure (EDP) after AoVPl using the \( t \) test, considered significant at \( p < 0.05 \). We also used the \( t \) test to compare perfusion times in survivors and nonsurvivors.

**Results**

**Clinical Study**

All patients are doing well, although one had postoperative hepatitis from which he recovered after 4 months. One patient has difficulty when running up stairs; all others have normal physical activity, and some patients even participate in sports. All patients receive anticoagulation therapy. Only one patient has no murmur at all, while most have a systolic murmur of grade II/IV at the base; one patient has a grade IV/IV murmur. Three patients have discrete aortic diastolic murmurs.

**ECG Changes**

The ECG changes are listed in table 2. There was no permanent disturbance of atroventricular conduction. Several patients developed a left anterior hemiblock (LAH), as might be expected, but we are concerned about two patients who have a complete right bundle branch block (RBBB) in addition to the LAH.

**Phono and Pulse Tracings**

Phonocardiography did not provide additional information. The pulse tracings were normal in all cases after operation, including those with an abnormal preoperative pulse tracing.

**X-ray**

The chest x-ray revealed only insignificant changes compared with the preoperative examination. The cardiothoracic ratio was preoperatively slightly above normal, with a mean of 54 ± 5.5% (range 47-64%). In one case the preoperative ratio of 65% was reduced to 51%. This was in the patient with additional mitral valve replacement due to insufficiency; the reduction in heart size is probably due to the restored mitral hemodynamics, and not to the AoVPl.

**Echocardiography**

Sixteen patients have been examined, including two who have not yet had a postoperative catheterization. Since nine patients were studied several times, 29 examinations were performed. Eleven patients were male and five were female. The age at the last examination ranged from 8.8–18.4 years (mean 12.7 ± 2.9 years). The mean time elapsed between operation and the last echocardiographic study was 9.2 ± 6.8 months (range 0.5–25.4 months). The following measurements were taken: speed of early diastolic closure-motion of the anterior mitral leaflet, anterior mitral leaflet motion amplitudes, maximum distance between the mitral leaflets in early diastole, left atrial diameter at the end of ventricular systole, left and right ventricular end-diastolic dimensions, and the thickness of the left ventricular posterior wall and interventricular septum. Echocardiographic values were considered normal if they were within one standard deviation of the mean.

In patients with body surface area up to 1.6 m², all measurements were compared with normal values from our laboratory, while for patients with a body surface area above 1.6 m² the normal values of Feigenbaum were used. The ratio of early diastolic distance between both mitral leaflets and the left ventricular end-diastolic dimension was determined in all but two patients: One had had mitral valve replacement, and no reliable measurement of mitral leaflets distance could be made in the other. Our normal value for this ratio is 0.6 ± 0.05. Septal motion was rated abnormal if it was flattened or paradoxical in at least some parts of the tracing. The motion of the prosthetic valve was considered normal if opening and closure were recorded as fast motions in due time relation to the ECG.

A summary of the echocardiographic measurements is given in table 3. The most striking phenomena are increased measurement of left atrial dimension in 11 patients and abnormal septal motion patterns in all but two patients. In most of the 14 patients with abnormal septal motion, there were marked differences between different areas of the septum, the motion pattern being normal toward the apex and becoming flattened or paradoxical at the base of the left ventricle, presumably at the site of the septal patch. With respect to regional differences in septal motion pattern in most of the patients, we made no attempt to take dynamic measurements, e.g., for fiber shortening and left ventricular ejection fraction. However, the ratio between early diastolic mitral leaflet separation and left ventricular internal dimension, which in our experience is a good parameter for left ventricular pump function, was normal in most patients.
Catheterization Studies

Fourteen patients, nine male and five female, were investigated at a mean interval of 7.5 ± 6.9 months (range 1–25 months) after operation. The mean age at the postoperative study was 12.1 ± 2.9 years (range 8.3–18.4 years). The mean gradient at rest was reduced from 94.7 ± 25.9 mm Hg (range 60–150 mm Hg) to 14.4 ± 17.2 mm Hg (range 0–65 mm Hg) at the postoperative study (fig. 4). Except for the patient with the highest gradient, no gradient exceeded 22 mm Hg at rest. The gradient was abolished in three cases (fig. 5). The patient with the residual gradient of 65 mm Hg is one of the earlier in the series and had only a #21 prosthesis inserted. He had the relatively high cardiac output of 6.8 l/min at study. This is one of the main reasons why we now insert larger prostheses.

No gradient increased more than 15 mm Hg under isoproterenol, and it did not increase at all in five patients (fig. 6). The isoproterenol test resulted in a moderate stress with a mean rise of cardiac index of approximately 20%. Four patients had gradients exceeding 10 mm Hg across the right ventricular outflow tract, the maximum being 37 mm Hg (fig. 7). These minor outflow gradients result from the bulging of the septal patch from the left ventricle into the right ventricular outflow tract, and the compensatory right ventricular outflow patch, which was too narrow.

<table>
<thead>
<tr>
<th>TABLE 3. Echocardiographic Measurements After Aortoventriculoplasty</th>
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<tbody>
<tr>
<td>Normal (mean ± sn)</td>
</tr>
<tr>
<td>Rate of early diastolic AML closure</td>
</tr>
<tr>
<td>Overall AML amplitude†</td>
</tr>
<tr>
<td>Opening AML amplitude‡</td>
</tr>
<tr>
<td>Mitral valve opening (MVO)‡ (distance between mitral leaflets in early diastole)</td>
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<tr>
<td>Prosthetic valve motion</td>
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<tr>
<td>Left atrial dimension</td>
</tr>
<tr>
<td>Left ventricular end-diastolic dimension (LVEDD)</td>
</tr>
<tr>
<td>Right ventricular end-diastolic dimension</td>
</tr>
<tr>
<td>Thickness of left ventricular wall</td>
</tr>
<tr>
<td>Thickness of interventricular septum</td>
</tr>
<tr>
<td>Motion pattern of interventricular septum</td>
</tr>
<tr>
<td>MVO/LVEDD</td>
</tr>
</tbody>
</table>

*Including one patient with a prosthetic mitral valve and one with idiopathic hypertrophic subaortic stenosis.
†Normal values not available for two patients with a body surface area > 1.6 m².
‡Abbreviation: AML = anterior mitral leaflet.

There was an insignificant increase in the left ventricular EDP after operation (fig. 8). But the postoperative EDP was 12 mm Hg or higher in six instances; the highest values were 22 and 27 mm Hg. In these two patients the preoperative pressures were not available for comparison. In 10 patients, comparison with a preoperative value was possible, but only twice was there an increase from a normal value to an EDP greater than 12 mm Hg. A pathological left ventricular EDP returned to normal after AoVPI in three patients.

The mean left ventricular dp/dt was not altered by AoVPI, and neither was the left atrial mean pressure. The mean right atrial mean pressure increased within normal values from 3.9–6.1 mm Hg. However, in three cases the pressure tracings from the right atrium were consistent with tricuspid valve insufficiency (fig. 9). The catheterization data are summarized in table 4.

In two cases, there was a small ventricular septal defect within the septotomy, but neither patient will
require reoperation. One was not shown by oximetry but discovered on the angiogram. In the other patient we measured a $Q_p/Q_s$ ratio of 1.2:1. Two other patients had very small, hemodynamically insignificant paravalvular leaks.

**Angiocardiology**

All angiograms showed satisfactory enlargement of the left ventricular outflow compared with the preoperative studies (figs. 10 and 11). The patient with a significant residual gradient, however, had an abrupt diminishing of outflow size at the prosthetic valve level (fig. 12). The contraction pattern was normal in the cases where cineangiograms were performed. The aorta proved to be too large in the initial series (fig. 13). This was later corrected by making the aortic part of the "inner" patch shorter, which produced an aortic base of a more appropriate size (fig. 10).

The most pronounced case of subpulmonic stenosis is shown in figure 7. Some patients had moderate angiographic narrowing of the outflow tract of the right ventricle without pressure gradient.

In the three cases with diastolic murmur, aortic insufficiency could only be seen in two aortograms. The third patient had a pronounced enlargement of the proximal ascending aorta without regurgitation, shown on the cineangiogram.

**Discussion**

Tunnel subaortic stenosis and narrow aortic annulus have been unsolved problems in cardiac surgery. The method reported here and elsewhere seems to be a more physiological solution to the problem than methods using extracardiac conduits.

The methods that involve patching at the aortic base only allow widening of the aortic ring to a very limited extent, and in subaortic stenosis no widening occurs. We agree with McGoon that an AoVPI with extension of the aortotomy posteriorly into the anterior mitral leaflet and consequent patch enlargement may be hazardous.

Good results were achieved with minimal residual gradient in all cases but one. The most striking echocardiographic features were abnormal septal motion patterns that could be due to alteration of left ventricular diastolic shape or decrease of septal contractions induced by operation or both. Although suggested by McGoon, the left ventricular performance did not seem to have been impaired by operation compared with preoperative values measured by echocardiography, angiocardiology and parameters derived from catheterization, i.e., left ventricular EDP, maximum left ventricular dp/dt and cardiac output. The capacity to increase cardiac output was also normal. Indeed, in all four patients with preoperative elevation of left ventricular EDP, the diastolic left ventricular function was improved, and left ventricular EDP returned to normal in three of them.

In the patient who required reoperation for

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**Figure 5.** Simultaneous recordings of left ventricle and ascending aortic pressures in a 15-year-old male before (A) and after (B) operation show the abolition of the preoperative gradient of 75 mm Hg. Note the change of QRS axis.
Figure 6. Simultaneous left ventricular and ascending aortic pressures in an 11-year-old girl with Noonan's syndrome and severe obstructive cardiomyopathy and pressure gradient of 125 mm Hg preoperatively. Panel A shows a pathological configuration of the systolic aortic pressure. The postoperative gradient at rest (B) remains below 25 mm Hg after Isuprel administration (C), and no Brockenbrough phenomenon occurs after the extrasystoles.
FIGURE 7. Right ventricular angiocardiogram in a 14-year-old male, the only patient with significant outflow tract stenosis of the right ventricle (37 mm Hg). The stenosis is well demonstrated in the lateral view. We now use a broader patch in the right ventriculotomy, with good results.

FIGURE 8. Individual changes of left ventricular end-diastolic pressure (LVEDP) before (preop) and after (postop) operation. Two patients developed elevated LVEDP postoperatively; in three patients it returned to normal. All patients lowered their LVEDP after isoproterenol. The mean LVEDP in 10 patients was practically unchanged after operation. Two patients had highly elevated LVEDP, but no preoperative value for comparison.

FIGURE 9. Right atrial pressure after aortoventriculoplasty suggestive of tricuspid insufficiency in a 12-year-old male. A similar tracing was also recorded in two other patients.

idiopathic hypertrophic subaortic stenosis, the marked mitral regurgitation disappeared even though the mitral valve was not touched at operation. We think this must have been caused by a slight posterior displacement of the margins of the anterior mitral leaflet due to enlargement of the aortic annulus. Thus, the anterior mitral leaflet might render relatively more valve material for closing the mitral opening. We can find no explanation for the possible tricuspid insufficiency in three cases.

The operative mortality of 24% has been very encouraging, especially since the deaths occurred in patients at high risk at the beginning of the series and because there have been no deaths in patients without previous cardiac surgery. The one death after injury of a septal coronary artery caused us to look very carefully at the coronary arteries in the angiocardiograms in the subsequent patients. Now, we are also careful even with patients who have very mild coarctation of the aorta.

ECG abnormalities did not contribute to death in any case; however, we are concerned about the future of the two patients with complete right bundle branch block and left anterior hemiblock because they may have a poor prognosis. The left anterior hemiblock can be explained by the septal incision. The lesion of the right bundle branch seems to have been caused by the deep septal suturing for the septal patch.

We do not know what the future will be for the children operated by this method, nor do we know how the septal incision and patching of the outflow will affect the ventricles in the long run. The long-term
prognosis of the artificial valves is also uncertain. Anticoagulant therapy gives rise to additional specific problems for pediatric patients. However, the results achieved in this group of patients are very promising. The immediate postoperative results are superior to those after conventional surgery. Since AoVPl is the more physiological approach to this therapeutic problem, we consider it to be the method of choice for tunnel subaortic stenosis, for valvular stenosis with narrow aortic ring, and whenever an aortic prosthesis inserted in childhood has to be replaced because of the patient’s growth, as well as a possible approach for severe idiopathic hypertrophic subaortic stenosis after previous unsuccessful conventional surgery, for aortic stenosis at multiple levels and when an aortic prosthesis becomes necessary in childhood, in order to have a larger prosthesis inserted and to delay reoperation.

**Table 4. Hemodynamic Data in Patients with Aortoventriculoplasty for Different Obstructions of the Left Ventricular Outflow Tract**

<table>
<thead>
<tr>
<th></th>
<th>Before surgery</th>
<th></th>
<th>After surgery</th>
<th></th>
<th>At rest</th>
<th>Isuprel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean ± sd</td>
<td>Range</td>
<td>n</td>
<td>Mean ± sd</td>
<td>Range</td>
</tr>
<tr>
<td>LV-aortic gradient at previous surgery</td>
<td>6</td>
<td>104.0 ± 21.3</td>
<td>70-135</td>
<td>6</td>
<td>93.2 ± 24.7</td>
<td>60-125</td>
</tr>
<tr>
<td>LV-aortic gradient at aortoventriculoplasty</td>
<td>15</td>
<td>94.7 ± 25.3</td>
<td>60-150</td>
<td>13</td>
<td>94.7 ± 25.3</td>
<td>60-150</td>
</tr>
<tr>
<td>Corresponding cardiac index (l/min/m²)</td>
<td>13</td>
<td>3.4 ± 1.1</td>
<td>2.6-6</td>
<td>12</td>
<td>3.9 ± 1.4</td>
<td>3.0-7.1</td>
</tr>
<tr>
<td>LVEDP</td>
<td>11</td>
<td>11.6 ± 4.1</td>
<td>5-19</td>
<td>13</td>
<td>10.0 ± 5.9</td>
<td>6-27</td>
</tr>
<tr>
<td>Left atrial mean pressure</td>
<td>9</td>
<td>10.0 ± 2.6</td>
<td>6-15</td>
<td>14</td>
<td>10.5 ± 9.4</td>
<td>0-37</td>
</tr>
<tr>
<td>RV-pulmonary gradient</td>
<td>14</td>
<td>5.2 ± 5.5</td>
<td>0-18</td>
<td>14</td>
<td>5.2 ± 5.5</td>
<td>0-18</td>
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<tr>
<td>RV-EVEDP</td>
<td>7</td>
<td>6.1 ± 2.9</td>
<td>3-12</td>
<td>14</td>
<td>6.1 ± 2.9</td>
<td>3-12</td>
</tr>
<tr>
<td>Right atrial mean pressure</td>
<td>10</td>
<td>3.9 ± 1.8</td>
<td>2.5-8.5</td>
<td>14</td>
<td>3.9 ± 1.8</td>
<td>2.5-8.5</td>
</tr>
</tbody>
</table>

All values are given in mm Hg.

Abbreviations: LV = left ventricular; LVEDP = left ventricular end-diastolic pressure; RV = right ventricle; RVEDP = right ventricular end-diastolic pressure.

**FIGURE 10.** A) Preoperative and B) postoperative left ventricular angiograms in a 9-year-old male showing the tunnel subaortic stenosis and its relief after operation. There was no residual gradient.
FIGURE 11. Same patient as in figure 6. Preoperative (A) retrograde and postoperative (B) transeptal left ventricular angiograms showing that the mitral insufficiency has almost completely disappeared after aortoventriculoplasty. There is a marked widening of the outflow tract and persistence of the typical deformation of the left ventricle.

FIGURE 12. Preoperative and postoperative left ventricular angiograms. This patient had a severe tunnel subaortic stenosis with a residual gradient of 90 mm Hg after previous conventional surgery (A). This gradient was reduced only to 65 mm Hg after aortoventriculoplasty because the Björk-Shiley valve was too small (#21). In the right anterior oblique position, the prosthetic valve looks like a “banding” in the outflow of the left ventricle (B).
renal failure postoperatively. Therefore, the overall mortality has decreased to 20.7%. The patient with transient atioventricular block now has a demand pacemaker.

References


Addendum

Since this paper was prepared for publication, additional patients have been operated upon, including adults. By November 1978, 29 operations had been performed. There has been one additional death from
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P G Björnstad, H Rastan, J Keutel, A J Beuren and J Koncz

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