PULMONARY ARTERY STENTING AFTER TOTAL SURGICAL CORRECTION OF RIGHT VENTRICULAR OUTFLOW TRACT OBSTRUCTIVE LESIONS

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Surgical correction has been the definitive therapy for right ventricular (RV) outflow obstructive lesions. Associated stenosis in pulmonary artery (PA) branches also requires surgery. Although these stenoses can be relieved by balloon dilatation, stent placement increases the success rate. In this study, we evaluate the results of stent implantation in residual PA stenosis after surgery. The study included to patients with previous surgery who required stenting of a PA or RV infundibulum or reballoning of an anery: 5 patients with tetralogy of Fallot, two with pulmonary atresia, one with pulmonary stenosis, one with truncus aneriosus, and one with a surgically patched ventricular septal defect and PA banding. The median age at implantation was 9.4 (range, 0.5 to 36) years and the mean bodyweight was 34.6 ± 21.2 kg. Twelve procedures were performed with 17 stents implanted. The stent was implanted eight times into the left, seven times into the right, and twice into the main PA or infundibulum. After stenting, there was a significant decrease in the RV pressure and trans-stenotic gradient and an increase in the vessel diameter. Two patients required surgery after stenting, one due to stent displacement into the right ventricle and the other for outflow tract reconstruction. Major complications included stent migration twice and failure to implant three stents. Our study demonstrates the efficacy and safety of stent implantation after surgical correction of pulmonary arterial lesions which negates the need for further surgery for residual lesions.

SURGICAL CORRECTION has been the definitive therapy for patients with tetralogy of Fallot. This entails the patch closure of the ventricular septal defect (VSD) and infundibulectomy, with or without pulmonary valvotomy. Associated stenotic lesions in the pulmonary artery (PA) branches may be found in tetralogy of Fallot, and surgical correction in such cases may be more complicated because of the involvement of the branch arteries. Surgery may also make the procedure more difficult and prolong its time. These problems also apply to other defects which involve right ventricular outflow tract (RVOT) obstruction.

Interventional catheter therapy has drastically changed the practice of cardiac catheterization and treatment of congenital heart diseases. Interventional catheter therapy has become an alternative or a supplement to surgical treatment.1 For some lesions, surgery has become virtually obsolete.2 Conventional surgery or balloon dilatation for PA stenosis has been unsatisfactory in many patients. Although 50% of PA stenoses can be relieved by balloon dilatation, stent placement increases the success rate from 70% to 80%.2 In adult cardiology, stents have been used extensively to support vessel walls in coronary and peripheral arteries.4 Nowadays, stents have become an important adjunct
in the management of children with congenital heart diseases.\textsuperscript{5}

In our study, we evaluate the results of stent implantation as a therapeutic procedure for residual PA stenosis after surgical correction of RVOT obstructive lesions, including peripheral PA stenoses.

Materials and Methods

Between February 1993 and June 1995, 25 patients underwent stent implantation at the Pediatric Cardiology Department at Guy's Hospital, in London. In ten of these patients, surgical correction alone was not sufficient; stent implantation into a PA or right ventricular (RV) infundibulum or reballoonning of an artery after surgery was required. There were 5 patients with tetralogy of Fallot (one with associated straddling tricuspid valve), 2 patients with pulmonary atresia and VSD, 1 patient with valvar and subvalvar pulmonary stenosis who had undergone surgical valvotomy and infundibulectomy before the era of balloon dilatation, 1 patient with a common arterial trunk and associated bilateral PA stenoses, and 1 patient with a VSD that was patched surgically, with placement of a band at the main PA. One patient with tetralogy of Fallot did not have a previous total correction but had a Pott's procedure instead (Table 1).

The age at stent implantation ranged between 6 months to 36 years (median, 9.4 years; mean, 12.68 ± 10.87 years) and bodyweight ranged between 4.88 to 69 (mean, 34.57 ± 21.21) kg. There were 4 males and 6 females. The median time interval between surgical correction and stent implantation was 4.72 (range, 0.44 to 35.23) years. The indications for stent implantations were PA stenosis with effort intolerance in five cases (42%), stenosis at the site of a shunt in two (17%), RV failure in two (17%), RVOT aneurysm in one (8%), and severe cyanosis in one (8%) (Table 1).

These patients represent a group in which total surgical correction could not be considered a final and definitive procedure. Patients in whom the stent was implanted before corrective surgery were excluded from the study. In one patient with pulmonary atresia, the stent was implanted before corrective surgery. However, this needed to be dilated one year after surgery. We did not exclude this case from the study because the surgical correction was insufficient to be considered as a final therapeutic measure.

The technique of stent implantation in the PA has been described previously.\textsuperscript{3} We reviewed the catheter-derived pressures and the stenotic PA diameter, before and after stenting, as well as the diameters and types of balloons used for dilatation.

A single procedure was sufficient in 7 patients (Table 2). Two patients required stenting twice. In one of them, the right PA was successfully stented, while attempts to stent the left PA were unsuccessful due to failure to pass the sheath through the stenotic artery. The artery was dilated by balloon without stent insertion. The left PA was successfully stented 3 months later.

In another patient, both the right PA (2 stents) and the left PA (1 stent) were successfully implanted at first attempt. Due to rising RV pressure, the procedure was repeated 7 months later, with implantation of the third stent into the right PA and balloon dilatation of the left PA. Afterwards, there was no need for further stenting.

In 4 patients, two stents were placed simultaneously in the same PA, and a third stent in one of them on a separate occasion. The number of stents implanted per patient was four in 1 patient, three stents in 1 patient, two stents in 2 patients, and a single stent in 6 patients (Table 2).

On eight occasions, the stent was implanted into the left PA (Figures 1-3), seven times into the right PA, and twice into the main PA or RV infundibulum (Table 2).

Blue Max balloons were used on seven occasions, Olbert balloons on four occasions, premounted...
stent-balloon assembly (Johnson and Johnson) was used three times, and Crystal (Bait) was used once. The balloon diameter ranged between 7 to 18 (mean, 11.13 ± 3.16) mm. The stents used were 1 to 3 (mean, 2.54 ± 0.88) cm long (Table 2).

Results

The study included 10 patients who had undergone twelve procedures. Seventeen stents were implanted at fifteen sites (Table 2).

Previous Management

Two patients with tetralogy of Fallot had modified Blalock-Taussig shunts before total correction, one patient had total correction without previous palliation, one patient had Pott's and Waterson shunts followed by laser-assisted balloon dilatation for acquired pulmonary atresia, and one patient had modified Blalock-Taussig and Pott's shunts followed by laser-assisted balloon dilatation (Table 1).

One child with pulmonary atresia had a left modified Blalock-Taussig shunt performed in the first year of life, followed by radiofrequency pulmonary valvotomy at the age of 5 years. One year later, the right major aorto-pulmonary collateral arteries were unifocalized, and a stent was implanted into the left PA nine days later. The other child with pulmonary atresia was corrected surgically.

In the patient with pulmonary stenosis who had surgical valvotomy and infundibulectomy in 1972, the stent was implanted into the left PA 21 years later because of residual stenosis in the left PA and decreased effort tolerance.

The infant with common arterial trunk had surgical repair at the age of 2 weeks, with stent implantation at both left PA and right PA 5 months later. The left PA stent was redilated after 7 months, with placement of another stent in the right PA.

One patient with a VSD had main PA banding at 47 days of age. The band was removed eight years later during surgical closure of the VSD. On follow-up, due to development of main PA stenosis, a stent was inserted 20 years after PA debanding.

Management Poststenting

In 2 patients, surgery was performed after stenting. In one patient with tetralogy of Fallot and RVOT aneurysm following total correction, the stent was displaced into the RV. Attempts to compress by snare were unsuccessful, and it was removed surgically 2 days postimplantation with repair of the stenotic left PA. In another child with pulmonary atresia, the RVOT was reconstructed surgically and the VSD closed 2 months after stenting of the left PA. The left PA was then dilated by balloon II months later (Table 2).

Hemodynamic Changes

The RV and aortic systolic pressures (AO), the systolic gradient (GR) across the stenotic vessel, the
Complications

Failure of the procedure or major complications were encountered during implantation of three of seventeen stents (17.65%) at fifteen sites. Two stent migrations occurred. One stent was displaced into a RVOT aneurysm, necessitating surgical removal and left PA repair 2 days later. In another patient, one of two stents implanted in the left PA was displaced proximally into the main PA across the right PA origin. This necessitated trimming of the kink in the left PA origin during corrective surgery one month later. Both stents were reballooned one year later.

Table 2. Characteristics of stems and dilating balloons.

<table>
<thead>
<tr>
<th>Patient Site of Implant</th>
<th>Length No. of Stent S (cm)</th>
<th>Balloon Diameter (mm)</th>
<th>Balloon Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>I LPA</td>
<td>3</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2 LPA</td>
<td>3</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>3 RPA</td>
<td>3</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>4a* RPA</td>
<td>3</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>4b LPA</td>
<td>3</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>5 RVOT</td>
<td>3</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>5b LPA</td>
<td>3</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>6b (LPA)+</td>
<td>-</td>
<td>-</td>
<td>(14)+</td>
</tr>
<tr>
<td>1 RPA</td>
<td>3</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>8 LPA</td>
<td>3</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>9a* RPA</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>9b RPA</td>
<td>1</td>
<td>1</td>
<td>7-10</td>
</tr>
</tbody>
</table>
| LPA - left pulmonary artery; RPA - right pulmonary artery; RVOT - right ventricular outflow tract; MPA - main pulmonary artery.

On a third occasion, we failed to implant a stent into the left PA due to failure to pass the sheath through, although there was successful implantation of another into the right PA. The left PA was dilated by balloon, and three months later it was successfully stented.

Two minor complications should be mentioned. Transient hypotension occurred once, with the catheters across both PA. On one occasion, the balloon (7 mm) ruptured while implanting a third stent into the right PA between two previously implanted ones. The stent was partially expanded, necessitating dilatation by two other balloons (8 mm and 10 mm). No mortality occurred in any procedure.

Discussion

Stent implantation is a new technique to treat residual stenosis of PA in congenital heart disease. This technique can be applied percutaneously for patients with long or multiple sequential stenoses. Intraoperative implantation can also be used in smaller children and in patients who have limited percutaneous access. The stents can also be applied in cases with significant vascular obstructive lesions in the immediate postoperative period, thus avoiding early reoperation in profoundly compromised children.

Stents have been implanted at different sites in children with congenital heart diseases. Apart from the PA and main branches, stents have been successfully implanted after atrio-pulmonary and cavo-pulmonary anastomoses, aortic coarctations, and congenital pulmonary vein stenosis. Patients with pulmonary atresia may also benefit from stenting after catheter perforation of the atresia by radiofrequency. Postoperative narrowing of a Fontan anastomosis has also been treated by stenting.

Table 3. Hemodynamic changes before and after stenting.

<table>
<thead>
<tr>
<th></th>
<th>Before stenting</th>
<th>After stenting</th>
<th>P &lt;0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>(Range)</td>
<td>Mean ± SD</td>
<td>(Range)</td>
</tr>
<tr>
<td>67.31 ± 22.15</td>
<td>(24 - 105)</td>
<td>53.42 ± 19.62</td>
<td>(28 - 100)</td>
</tr>
<tr>
<td>105.31 ± 82.68</td>
<td>(92 - 120)</td>
<td>113.5 ± 16.50</td>
<td>(90 - 139)</td>
</tr>
<tr>
<td>48.71 ± 28.78</td>
<td>(3 - 98)</td>
<td>11.67 ± 19.36</td>
<td>(0 - 70)</td>
</tr>
<tr>
<td>0.65 ± 0.24</td>
<td>(0.2 - 1.05)</td>
<td>0.49 ± 0.21</td>
<td>(0.23 - 0.91)</td>
</tr>
<tr>
<td>5.63 ± 2.05</td>
<td>(2.3 - 8.6)</td>
<td>10.25 ± 3.00</td>
<td>(6.5 - 16.8)</td>
</tr>
</tbody>
</table>
Our data demonstrate that PA stenting can provide effective relief of residual obstructions after surgical correction. The procedure was safe in our cases with no mortality. The immediate results are satisfactory, with a significant decrease of the gradient and RV pressure and an increase in the diameter of the stenotic lesion. Successful implantation of stents was achieved in ten of twelve procedures (83.33%) or in fourteen of the seventeen stents implanted (82.35%). Failure or unsuccessful implantation was encountered in 17.65% of our cases (twice due to migration and once due to failure to implant). Repeat catheterization showed that all stents remained patent in all cases, with only one vessel requiring restenting and three requiring redilating of the stent.

These data are consistent with previous reports. Ing et al9 reported a 97% patency rate at follow-up of stented PA and a 94% success rate in repeat dilatation and restenting of these vessels. Mendelsohn et al,3 however, reported restenosis occurrence within stents that have been applied to congenital pulmonary vein stenosis in two of three patients.

We conclude that this study demonstrates the efficacy and safety of stent implantation after surgical correction of pulmonary arterial lesions. Besides facilitating corrective surgery when performed before surgery, stent implantation also negates the need for further surgery for residual lesions. Thus, surgery is not always a final therapy.

References