Implantation of endovascular stents for hypoplasia of the transverse aortic arch

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Abstract. Hypoplasia of the transverse aortic arch is commonly associated with aortic coarctation. Persistent or recurrent obstruction can occur at this level after successful repair of the native coarcted segment. The purpose of this report is to present a new technique to treat such lesions, namely with implantation of a balloon-expandable stent. This approach was used successfully in 4 children with such hypoplasia occurring after repair of coarctation. Implantation led to both anatomical and physiological relief of obstruction in all. The patients tolerated the procedure, and there were no major adverse events.

Keywords: stent, transverse aortic arch

Intravascular stents have been used successfully to treat a variety of congenital and postoperative stenoses. This therapeutic implant appears particularly suited for hypoplastic vascular lesions, in which, with balloon dilation alone, there is either the potential for a recurrent stenosis or for formation of aneurysms. Several experimental studies and early clinical reports have demonstrated the feasibility and immediate effectiveness of placing a balloon expandable stent in the patient with aortic coarctation or recoarctation. Hypoplasia of the transverse arch is a common finding associated with aortic coarctation. Residual obstruction can occur at this level after successful repair for the native coarcted segment, either after surgery or balloon dilation. The surgical techniques designed to address this problem carry a higher morbidity and mortality rate than does conventional repair for aortic coarctation due to the risks associated with the reduction in flow of blood to the brain required to accomplish the repair. This report notes our preliminary experience in 4 such patients treated by implantation of endovascular stents.

Material and methods
Clinical data: Between September 1997 and January 1999 we inserted stents in four patients with hypoplasia of the transverse aortic arch (Table 1). All had previously undergone surgical repair of coarctation, 3 with a subclavian flap technique (No 1–3) and 1 with end-to-end anastomosis. The median time between the operation and the implantation was 11 (range, 11–13) years. In 3 (No 1, 2, and 4), the aortic arch was described as normal in size at the time of surgery. In the other patient, surgical observations were not available. All patients were asymptomatic, presenting with systolic hypertension and a clinical diagnosis of recurrent obstruction in the aortic arch. Three patients (No 1, 2, and 4) were receiving vasoconstrictors, and 1 patient (No 3) was receiving propranolol and diuretics for hypertension. Table 1 summarizes the demographic data.

Procedure
Informed consent was obtained for each procedure. Under general anesthesia, percutaneous entry was achieved into the right femoral artery and vein...
Table 1. Characteristics of the patients.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Associated lesions</th>
<th>Medication</th>
<th>Age at CoA repair</th>
<th>Age at stent implantation</th>
<th>Weight</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>BAV, VSD</td>
<td>enalapril</td>
<td>5y5m</td>
<td>17 y</td>
<td>78 kg</td>
<td>171 cm</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>BAV</td>
<td>enalapril</td>
<td>3y7m</td>
<td>14 y</td>
<td>65 kg</td>
<td>170 cm</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td></td>
<td>propranolol diuretics</td>
<td>1y5m</td>
<td>12 y</td>
<td>50 kg</td>
<td>151 cm</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>VSD, MV prolapse</td>
<td>enalapril</td>
<td>1y</td>
<td>13 y</td>
<td>45 kg</td>
<td>164 cm</td>
</tr>
</tbody>
</table>

CoA = coarctation of the aorta, BAV = bicuspid aortic valve, VSD = ventricular septal defect, MV = mitral valve

Transatrial septal puncture allowed access from the left atrium, through the left ventricle, to the ascending aorta. The aortic pressure, and the peak-to-peak gradient, were measured simultaneously in the ascending and descending aorta. The aortic diameter was measured angiographically at the ascending aorta, the transverse arch, the isthmus, and the operative site for removal of the coarctation and at the diaphragm. The degree of hypoplasia of the transverse arch was defined as the ratio of the diameter of the aorta at the transverse arch, to the diaphragmatic aorta. An aneurysm at the site of the surgical repair was defined as a ratio of the site of repair to the diaphragmatic aorta greater than 1.5.

The antegrade balloon-tipped catheter, was placed whilst deflated, within the proximal left common carotid artery (Fig. 1) to allow retrograde positioning of the stent into the transverse arch, distal to the carotid artery. The flow of blood in the left carotid artery was monitored with a Doppler transducer tapped to neck during the procedure.

Implantation of the stent (Palmez P4014 or P5014, Johnson & Johnson Interventional Corp., Warren, NJ) was performed using standard technique utilizing a long 11 or 12 French sheath and an extra-stiff interventional guide wire. After implantation, pressures were measured simultaneously in the ascending and descending aorta, and angiography was performed in the ascending aorta.

The children were observed overnight and discharged home the following morning. All received 2 intravenous doses of cephalixin (40 mg/kg). Heparin sulphate was administered during the procedure (150 IU/kg) and a low dose of continuous heparin (10 IU/kg/hr) was given overnight after the procedure. Daily acetosalicylic acid was begun for 6 months the following morning.

Statistical methods

Data are expressed as mean ± standard deviation or median and range when appropriate. Paired
Students' t test was used to compare the variables before and after implantation of the stent. The level of significance was chosen at p < 0.05.

Results

Angiographic and hemodynamic results: All patients had significant hypoplasia of the transverse arch distal to the left common carotid artery, with an unobstructed site of coarctation. The second patient had a small aneurysm at the site of the previous repair. Implantation was successful in all patients. The hemodynamic and angiographic results are presented in Table 2. After implantation and final dilation, the gradients were completely abolished in 3 patients. The peak-to-peak gradient decreased from 27 ± 7 to 2 ± 4 mmHg (p < 0.001). The stenosis seen angiographically was relieved, with the luminal diameter increasing from 10 ± 2 mm to 16 ± 2 mm (p = 0.01). The ratio of the diameter of the transverse aortic arch to the descending aorta at the level of the diaphragm increased from 0.50 ± 0.05 to 0.80 ± 0.04 (p < 0.01). In the fourth patient, the left subclavian artery remained patent after implantation of the stent between the left carotid and the left subclavian arteries. Total fluoroscopy time was 27 ± 10 min. All children were discharged home on the following day on either vasodilators (no 1, 2, and 4) or propranolol and diuretics.

Complications

All patients tolerated the procedure and no major adverse events were encountered. A reduced pulse at the site of arterial entry was detected in the third patient. In the fourth patient, an asymptomatic pseudoaneurysm of the right femoral artery was noted one month after the procedure. The pseudoaneurysm was repaired surgically after attempted embolization with a coil had failed, and the child recovered uneventfully. This fourth child also had paradoxical hypertension after the procedure, which was controlled with nifedipine.

Clinical follow-up

The patients were followed up from 6 to 16 months, with an average follow-up of 11 months. There have been no late complications, infections, thromboses, embolus, or other problems related to the stent throughout the entire period of follow-up. All patients are asymptomatic and normotensive.

Discussion

These cases demonstrate another potential application for the percutaneous deployment of endovascular stents in children. Placement of large stents, rated to over 15 mm (maximal diameter 25 mm) in the transverse aortic arch led to anatomical and physiological relief of stenosis in all children with hypoplasia of the transverse aortic arch after repair of coarctation.

Such hypoplasia is present in some neonates with aortic coarctation, presumed due to decreased flow across the aortic arch in utero. With early repair, such associated hypoplasia has been shown to undergo better growth when addressed in early infancy than in children operated on beyond 1 month of age. A variety of surgical techniques have been used to repair aortic coarctation, each with its own advantages and disadvantages. Despite satisfactory repairs with different techniques, the proximal transverse aortic arch often remains smaller than normal after surgery. Pinzon and coworkers detected hypoplasia of the transverse arch or isthmus in two-fifths of patients previously operated for coarctation of the aorta during a 13-year follow-up, more commonly associated with septal defects or obstruction of the left ventricular outflow tract. This residual hypoplastic tubular segment, usually between the left common carotid and the left subclavian arteries, can contribute to a persistent or recurrent gradient after repair. In this study, 3 of the 4 patients had undergone subclavian flap aortoplasty, and one had an end-to-end-anastomosis, all at an age of

<table>
<thead>
<tr>
<th>Patient no</th>
<th>Peak-to-peak pressure gradient (mmHg)</th>
<th>Vessel diameter (mm)</th>
<th>TAA/aorta at diaphragm ratio</th>
<th>Balloon diameter (mm)</th>
<th>Stent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>0</td>
<td>12</td>
<td>18</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>0</td>
<td>10</td>
<td>18</td>
<td>0.45</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>8</td>
<td>7</td>
<td>14</td>
<td>0.47</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>0</td>
<td>11</td>
<td>15</td>
<td>0.55</td>
</tr>
</tbody>
</table>

TAA = transverse aortic arch
greater than one year. In 3 patients, the aortic arch had been described as normal at the time of the surgery but had failed subsequently to grow normally. In no patient was there a recoarctation at the site of the surgical repair. The hypertension, and the arch obstruction within the arch were related to discrepancies in growth of the transverse aortic arch proximal to the site of repair.

Formation of aneurysms at the site of surgical repair of coarctation is also related to associated hypoplasia of the transverse arch.\textsuperscript{20} The dynamic phenomena, of acceleration of flow and turbulence, originating within the narrow transverse arch, and directed toward the site of repair contributes to formation of the aneurysm. Interestingly, in the second of our 4 patients, such an aneurysm at the site of repair was noted but did not interfere with placement of the stent. Surgical treatment for an hypoplastic segment associated with coarctation is a technically demanding procedure.\textsuperscript{21,22} It generally involves an anterior midline approach, cardiopulmonary bypass, and often profound hypothermic total circulatory arrest. As such, a percutaneous technique appears attractive in avoiding surgical morbidity if the technique allows both immediate and long term control of blood pressure.

While percutaneous balloon angioplasty has been used for more than a decade in treating patients with aortic coarctation, this technique can lead to formation of aneurysms, or result in an inadequate or temporary relief of the stenosis often related to anatomical rather than technical issues.\textsuperscript{9} Adjunctive implantation of stents in selected patients provides a method for overcoming these limitations of balloon angioplasty, and in this setting, the often elastic and distensible transverse arch, which, in the absence of any discrete obstructive stenosis as in coarctation, recoils after dilation. Additionally, percutaneous implantation has been shown to be a technically feasible method for treatment of idiopathic and traumatic aneurysms of the aorta.\textsuperscript{23}

The use of rigid stents in the growing child raises the possibility of an acquired stenosis from the fixed diameter of the implant.\textsuperscript{4,24} Implantation, however, clearly has a role in patients at or close to adulthood size as in our experience. Of concern in the setting of stent implantation in the transverse aortic arch is the potential for compromised flow of blood to the main arterial branches arising from the aortic arch. To avoid this, during the implantation, a Doppler transducer can be used to record the flow in the carotid artery. In addition, an antegrade catheter can be used as a landmark, to avoid stent deployment at the orifices of the head and neck vessels. Other potential complications in this, and other procedures, include embolization or misplacement, formation of aneurysms, restenosis due to intimal overgrowth, and femoral arterial complications from the large sheath required for implantation. Re-expansion of the stent is possible when positioned in a child whose growth is not complete.\textsuperscript{21}

For patients with hypoplasia of the transverse aortic arch occurring after repair of coarctation of the aorta therefore, implantation of stents can be considered a possible alternative to surgery. In the fully grown patient, placement of stents is particularly attractive, since further intervention is not likely with fully expanded devices.

References

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