Percutaneous Balloon Angioplasty for Native Coarctation of the Aorta

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Twenty-six children, aged 5 weeks to 14.7 years, underwent percutaneous balloon angioplasty for a discrete native coarctation of the aorta. The procedure reduced the systolic coarctation gradient acutely in all children. The mean systolic gradient decreased by 75%, from 48.6 ± 2.4 before to 12.3 ± 1.9 mm Hg after angioplasty (p < 0.001). Long-term results were evaluated in 14 children by follow-up catheterization 12 to 26 months (mean 15.3) after angioplasty. At follow-up, the residual gradient averaged 11.7 ± 3.7 mm Hg (range -5 to 36) and had not changed from that measured immediately after angioplasty (p = 0.64). Compared with preangioplasty values, the systolic pressure in the ascending aorta had improved substantially at follow-up (116.0 ± 3.2 versus 143.9 ± 3.1 mm Hg, p < 0.001).

On the basis of follow-up data, two groups of children were identified: Group 1 consisted of nine children with a good result, defined as a residual gradient <20 mm Hg and no aneurysm; Group 2 consisted of five children with a poor result, four with a residual gradient >20 mm Hg (range 25 to 36) and one with an aneurysm at the dilation site. There was no statistical difference between the two groups in age at angioplasty, balloon size, ratio of balloon to isthmus diameters, follow-up duration, heart rate or cardiac output. However, of the four children with a residual gradient >20 mm Hg, two were the youngest in the study, and in two the aorta was inadvertently dilated with a balloon 4 to 5 mm smaller than the isthmus diameter. There was a significant difference between groups in the systolic coarctation gradient before angioplasty. All children whose preangioplasty gradient was <50 mm Hg had a good outcome, while five of six children whose preangioplasty gradient was ≥50 mm Hg had a poor long-term result (Fisher exact test, p = 0.003). Thus, a good long-term result was documented in 64% of patients and appears most likely to be achieved in children with a preangioplasty gradient <50 mm Hg. Percutaneous balloon angioplasty may provide an effective nonsurgical approach to some children with a native coarctation.

Although surgical repair is considered conventional treatment for coarctation of the aorta, the long-term results have been less than optimal. Late restenosis (1–3) and aneurysm formation (4,5) have been disturbing sequelae of surgical repair, and the surgical procedure itself may be associated with significant morbidity and mortality (6,7). Recently, percutaneous balloon angioplasty has been used in small series as an alternative to surgical repair for children with coarctation of the aorta (8–15). Angioplasty appears to be effective in recurrent postoperative coarctation, and is now considered by some to be the treatment of choice for this condition (16). The use of balloon angioplasty for native coarctation, however, is more controversial. Angioplasty has been found to acutely reduce the gradient of a native coarctation, but results in small series have suggested that such relief may be short-lived (8,11) or that late aneurysm formation may occur (15,17).

Since 1984, percutaneous balloon angioplasty has been used at the University of Michigan as an experimental alternative to surgery in 26 children with a native coarctation of the aorta. The purpose of this report is to describe our experience with balloon angioplasty in these children, with emphasis on the long-term results in the first 14 who have been reevaluated at cardiac catheterization 12 months or more after angioplasty. Early and late results will be compared, complications will be reviewed, and risk factors for a poor long-term result will be assessed.
Methods

Study patients. Since June 1984, 26 children have undergone percutaneous balloon angioplasty for a native coarctation at the University of Michigan. The procedure was approved by the hospital institutional review board as an experimental alternative to surgical repair and informed consent was obtained for each study. Eligibility criteria included the presence of a discrete thoracic coarctation with a resting systolic gradient of ≥30 mm Hg and systolic hypertension in the arms with or without congestive heart failure. Children with a long-segment coarctation or severe isthmic hypoplasia were not candidates for angioplasty. During the first 18 months of the study, children under 6 months of age were also excluded. More recently, with the availability of smaller angioplasty catheters, we have utilized balloon angioplasty in infants as young as 5 weeks of age.

Angioplasty procedure. Percutaneous balloon angioplasty is performed in the cardiac catheterization laboratory with the patient lightly sedated. With local lidocaine anesthesia, a pigtail catheter is inserted percutaneously into each femoral artery. A 5-7F catheter is advanced into the ascending aorta, and a 4-7F catheter is positioned in the descending aorta to monitor distal pressure. A thermodilution catheter is positioned in the pulmonary artery for measurement of cardiac output before and after angioplasty. Each patient is given heparin, 100 units/kg body weight (maximal dose 3,000 units). The coarctation pressure gradient is measured from simultaneous ascending and descending aorta pressure tracings. An ascending aortogram is then filmed in the anteroposterior and lateral projections. An electrode catheter, with a known interelectrode distance, is positioned in the superior vena cava to permit correction of the magnification factor. If after angiography the coarctation is judged inadequate, a balloon catheter is chosen whose inflated balloon diameter is equal to the diameter of the isthmus just distal to the left subclavian artery. If the isthmus diameter falls between two balloon sizes, the smaller balloon is used. A Mansfield Scientific angioplasty catheter has been utilized in most cases, but recently we have used the Schwartz catheter (a 5 mm balloon on a 4.7F shaft) in infants. The balloon catheter is advanced over a 0.035 inch (0.88 cm) J-tipped exchange wire positioned in the ascending aorta. The deflated balloon is placed across the coarctation and is inflated to 4 to 6 atmospheres (or until the waist disappears) for 5 to 10 seconds using a dilute mixture of saline solution and contrast medium. Balloon inflation is repeated three to five times with slight changes in catheter position to assure optimal dilation of the coarctation. The balloon catheter is then removed and a pigtail catheter is advanced over the exchange wire to the ascending aorta. Pressures are again recorded in the ascending and descending aorta, thermodilution cardiac output is measured and an ascending aortogram is filmed. All catheters are then removed and hemostasis is obtained with local pressure. The patients are observed in a moderate care setting for 24 hours after the procedure.

Follow-up study. Fifteen of the 26 patients have been followed up for ≥12 months after balloon angioplasty, and 14 have undergone repeat cardiac catheterization and angiography to document the long-term result. The family of one patient, an 8 year old boy who experienced a cerebrovascular accident during the angioplasty procedure, has refused a repeat catheterization, but no aneurysm was noted on follow-up nuclear magnetic resonance (NMR) imaging. In each child the repeat catheterization has included simultaneous measurement of ascending and descending aortic pressures, thermodilution cardiac output and a biplane ascending aortogram. An aneurysm was diagnosed in the presence of: 1) fusiform dilation at the coarctation site with a diameter ≥150% of the aortic diameter at the diaphragm (4); or 2) a discrete saccular dilation at the site not present on the preangioplasty aortogram.

Statistical analysis. All pressure gradients referred to in this report were obtained at cardiac catheterization by direct measurement of ascending and descending aortic pressures. Data are expressed as mean ± 1 standard error (SE) of the mean. Data obtained immediately before and after angioplasty and at follow-up are compared using a two-tailed t-test for paired observations. Group data are compared using a group Student’s t-test. For all analyses a p < 0.05 value is required as evidence of a significant effect.

Results

Clinical features. The 26 children ranged in age from 5 weeks to 14.7 years (mean 6.3 ± 0.9) and in weight from 4.4 to 60 kg (mean 22.9 ± 3.0). The group consisted of 15 boys and 11 girls, including 5 with Turner’s syndrome. Associated cardiovascular lesions included a bicuspid aortic valve (seven patients), mild valvular aortic stenosis (one patient), moderate subvalvular aortic stenosis (one patient), a small patent ductus arteriosus (four patients), a small ventricular septal defect (one patient), mild mitral stenosis (one patient) and an aortoventricular septal defect with dextrocardia and a right aortic arch (one patient). Two infants (aged 5 weeks and 6 months, respectively) presented with congestive heart failure. All 26 children had systolic hypertension in the arms. A 5 year old boy had undergone attempted surgical repair 2 years earlier, but the procedure was aborted in the operating room when his collateral circulation was judged inadequate.

Angioplasty results. Percutaneous balloon angioplasty was performed with balloons ranging from 5 to 20 mm in diameter. The procedure acutely reduced the systolic coarctation gradient in every child. The mean systolic gradient decreased by 75%, from 48.6 ± 2.4 mm Hg before angio-
plasty to 12.3 ± 1.9 mm Hg after angioplasty (p < 0.001). The systolic pressure in the ascending aorta decreased from 141.0 ± 2.7 to 127.5 ± 3.0 mm Hg (p < 0.001); the systolic pressure in the descending aorta increased from 92.4 ± 1.9 to 115.3 ± 2.8 mm Hg (p < 0.001). There was no significant change in heart rate or cardiac output after angioplasty.

There were no deaths associated with balloon angioplasty. An 8 year old boy experienced a cerebrovascular accident during the procedure and developed a moderate hemiparesis that was nearly resolved 1 year later. Transfusion was required in one child after excessive bleeding occurred from the arterial puncture site. Arterial pulse loss occurred in four children, but all pulses returned with 24 to 48 hours of heparin therapy. Thrombolytic agents were not used in any patient.

Follow-up data. Fourteen children underwent a follow-up cardiac catheterization and aortography 12 to 26 months (mean 15.3) after balloon angioplasty (Fig. 1 and Table I). In these children, angioplasty acutely decreased the systolic coarctation gradient from 47.6 ± 3.0 to 13.0 ± 3.4 mm Hg (p < 0.001) and the systolic pressure in the ascending aorta from 143.9 ± 3.1 to 134.1 ± 4.2 mm Hg (p < 0.01), without a change in heart rate or cardiac output. At follow-up 15.3 months later, the residual gradient averaged 11.7 ± 3.7 mm Hg (range -5 to 36) and had not changed from that measured immediately after angioplasty (p = 0.64). Compared with preangioplasty values, the systolic pressure in the ascending aorta had improved substantially at follow-up (116.0 ± 3.2 mm Hg, p < 0.001). Compared with measurements made immediately after angioplasty, there was a small but significant increase at follow-up in the aortic diameter at the coarctation site (9.8 ± 1.1 versus 8.9 ± 1.1 mm, p = 0.02) and in the ratio of coarctation site to isthmus diameters (0.82 ± 0.05 versus 0.76 ± 0.04, p = 0.03). These data, which exclude the one child with an aneurysm, suggest that anatomic remodeling may have occurred at the dilation site after balloon angioplasty.

Nine children were regarded as having a good long-term result (Table I), which is defined as a residual gradient <20 mm Hg and no aneurysm at follow-up. These nine children had a mean residual gradient of 4.3 ± 2.0 mm Hg (Figs. 2 and 3). Five children were considered to have a poor long-term result because of a residual gradient >20 mm Hg in four children and a small aneurysm at the dilation site in one child (Fig. 4). There was no statistical difference between the two groups in age at angioplasty, balloon size, ratio of balloon to isthmus diameters, follow-up duration, heart rate or cardiac output. However, of the four children with a residual gradient >20 mm Hg, two were the youngest in this series (Patients 10 and 11) and in two the coarctation was inadvertently dilated with a balloon 4 to 5 mm smaller than the isthmus diameter (Patients 12 and 14). There was a significant difference between groups in the systolic coarctation gradient before angioplasty. The preangioplasty gradient averaged 41.3 ± 2.7 mm Hg (range 32.0 to 52.0) in children with a good result, compared with 59.0 ± 2.5 mm Hg (range 52.0 to 66.0) in those with a poor long-term result (p < 0.001). All children whose preangioplasty gradient was <50 mm Hg had a good outcome, whereas five of six children whose preangioplasty gradient was ≥50 mm Hg had a poor long-term result (Fisher's exact test, p = 0.003).

Clinical response. A beneficial clinical response at follow-up was observed in the majority of patients 12 to 26 months after coarctation angioplasty. Before angioplasty, all 14 children were hypertensive (right arm systolic pressure at rest exceeding the 95th percentile for age and sex). At follow-up, hypertension had resolved completely in 10 children and was diminished in 3 others. Leg claudication had resolved completely in 10 children and was diminished in 3 others. Leg claudication had resolved in all four children who experienced it before angioplasty. The infant with congestive heart failure had complete resolution of symptoms after coarctation angioplasty. Patients 11 and 14 remained hypertensive, had a significant residual coarctation gradient at follow-up and underwent successful surgical repair. An 8 year old boy with an aortic aneurysm remained asymptomatic and had no progression in aneurysm size detected by NMR imaging 6 months after his follow-up catheterization.

Discussion

The data presented indicate that percutaneous balloon angioplasty is an effective treatment alternative to surgery in some children with a native coarctation of the aorta. Nine
Table 1. Pertinent Data Regarding 14 Children Treated With Percutaneous Balloon Angioplasty for a Native Coarctation and Followed Up for 12 to 26 Months

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Group 1 (gradient <20 mm Hg and no aneurysm)

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Group 2 (gradient >20 mm Hg or aneurysm)

Aorta Syst = aortic systolic pressure; Coarc Grad = systolic coarctation gradient; Ratio CoIsth Dia = ratio of coarctation site to isthmus diameters; SEM = standard error of the mean.
of 14 children (64%) followed up for ≥12 months after angioplasty were documented to have a good result, with a mean residual gradient of 4.3 mm Hg. Hypertension either resolved or decreased in all but one child and symptoms of claudication resolved in all affected children. Four children had a residual gradient >20 mm Hg at follow-up (two were infants, and in two the coarctation was dilated with a balloon 4 to 5 mm smaller than the isthmus) and another child was found to have an aneurysm at the dilation site. These findings are based on data obtained at cardiac catheterization and angiography at an average of 15.3 months after angioplasty, and constitute the longest follow-up study to date of angioplasty for native coarctation.

**Previous studies.** Our findings are consistent with those reported in a small number of previous studies (10,12–14). Lababidi et al. (12) for example, described their experience...
with balloon angioplasty in 20 children with a native coarctation. The procedure was performed without mortality or serious morbidity and acutely decreased the coarctation gradient from 53 to 10 mm Hg. Nine children underwent repeat catheterization an average of 8.6 months after angioplasty and were found to have a mean residual gradient of 17.7 mm Hg (range 0 to 32). In only two children, both neonates, had the follow-up gradient increased appreciably from that measured immediately after angioplasty. Clinical improvement was noted in all symptomatic children and no aneu-

**Figure 4.** Patient 13. **A,** Preangioplasty aortogram of an 8 year old boy who had a 52 mm Hg coarctation gradient. **B,** Follow-up aortogram 26 months later demonstrates a small saccular aneurysm at the angioplasty site. A 1 mm Hg residual gradient was present.

rusms were encountered. Similarly, Cooper et al. (13) reported favorable short-term results from percutaneous balloon angioplasty in five children with a native coarctation. Angioplasty reduced the coarctation gradient from 35–70 to 0–10 mm Hg in these patients without any serious short-term complications.

**Long-term effectiveness of angioplasty.** In contrast, others have questioned the long-term effectiveness of balloon angioplasty for native coarctation (8,10,11,17). Of particular concern has been recurrent stenosis, especially in infants, and late aneurysm formation. Finley et al. (11) reported clinical evidence of early restenosis in two of four newborns by the 4th day after angioplasty; one child was well palliated, however, and did not require surgical repair until 8 months of age. Of the other two infants in their report, one had an excellent long-term result and the other died after catheter perforation of the angioplasty site. Lock (8) and Sperling (10) and their coworkers also described early recurrence of coarctation in a small number of infants (n = 3) treated with balloon angioplasty. The neonate in the report by Sperling et al. improved clinically, however, and early surgery was avoided. In our series, heart failure resolved completely in the two infants with failure at presentation, despite only modest gradient relief in the 6 month old. Although these small series suggest that angioplasty may achieve less than ideal gradient relief in infants, several infants have experienced excellent palliation from the procedure (10–12). In these patients, surgical repair may be postponed to an older age when long-term results of surgery are also more favorable (1–3). Further, with refinements in angioplasty catheters and technique, the results in this age group can be expected to improve.

**Late aneurysm formation.** This is also a concern after balloon angioplasty of native coarctation. Lock et al. showed in an animal model (18) and in excised human aortas with coarctation (19), that angioplasty produces intimal and medial tears. The lesions were completely healed by 2 months, however, and transmedial tears were observed only if the balloon had been overdistended or ruptured. Marvin et al. (17) reported evidence of aneurysm formation at the dilation site in 6 of 11 children with a native coarctation evaluated 7 to 14 months after angioplasty. Pathologic examination of resected aneurysms revealed intact adventitia, linear medial tears and local medial thinning. More recently, Cooper et al. (15) reported aneurysmal dilation in three of seven children evaluated 14 months after angioplasty. In contrast, in the largest angiographic follow-up study to date, we identified an aneurysm in only 1 of 14 children. In a 15th child, no evidence of an aneurysm was found on NMR imaging. Similarly, no aneurysm was found in the 11 children reported by Lababidi (12) or Allen (14) and their coworkers. The difference in reported incidence of aortic aneurysm after angioplasty may relate to balloon size, the nature of the coarctation undergoing dilation or to the investigators’ def-
inition of an aneurysm. We concur with Morrow et al. (20), who observed that some irregularities of the aortic contour noted after angioplasty can be demonstrated, by high quality angiography, to be present before angioplasty. It is clear that more studies are needed to assess the long-term risk of aneurysm formation after angioplasty and to determine how this risk compares to that after surgical repair (4.5).

**Recommendations.** The role of percutaneous balloon angioplasty in the treatment of children with a native coarctation remains to be defined. The data presented in this report, however, suggest that angioplasty may prove valuable in a number of ways. First, angioplasty may replace surgery altogether for some children. Our data suggest that this is most likely for children whose preangioplasty gradient is <50 mm Hg. We, and others (14), have had the impression that children with a “membranous” coarctation (very discrete with a well developed aorta just proximal and distal to the stenosis) respond most favorably to angioplasty (Fig. 2). Because discrete membranous coarctations generally have a modest gradient, the 50 mm Hg threshold noted in our study may relate to this anatomic substrate. Angioplasty may be particularly suited for this type of coarctation, which often has a poorly developed collateral circulation and therefore may carry an increased surgical risk. Second, angioplasty may offer an effective palliative approach to coarctation in early infancy. There are few data in this age group, but it appears that gradient relief may be less complete and recurrence of stenosis more common than in older children. Nevertheless, angioplasty may provide effective nonsurgical palliation until an infant attains an age at which long-term surgical results are also more favorable (1.3). More longitudinal data are necessary to evaluate the risks of restenosis and aneurysm formation before balloon angioplasty is used routinely to treat native coarctation. Until such data become available, it is recommended that the procedure be performed only in the context of an approved investigative protocol.

**References**


