Balloon Angioplasty for Recurrent Coarctation of Aorta
Immediate and Long-term Results
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Background. As angioplasty techniques have been refined and larger low-profile balloons developed, a nonsurgical approach to recoarctation has become available. Several reports have documented both the efficacy and safety of this procedure. However, there are little data available on the long-term follow-up of these patients. This report details the initial results and long-term evaluation of both the relief of obstruction and the presence of hypertension after balloon angioplasty for recurrent coarctation.

Methods and Results. Balloon angioplasty for recurrent coarctation of the aorta was performed 29 times in 26 patients at a median age of 4 years and 9 months (range, 4 months to 29 years), with eight patients less than 1 year old. Initial surgical techniques were end-to-end anastomosis in 11 patients, subclavian flap aortoplasty in 11 patients, and patch aortoplasty in four patients. Angioplasty was performed at a median interval of 2 years and 7 months (range, 4 months to 23 years) after surgery. Mean peak systolic pressure difference across the coarctation decreased from 40.0±16.8 to 10.3±9.5 mm Hg (p<0.05) after the initial angioplasty, and mean diameter of the aortic lumen at the coarctation site increased from 5.8±3.5 to 9.0±4.3 mm (p<0.05). There was no mortality, and only one patient developed an aneurysm (4%). Three patients underwent repeat angioplasty for a pressure difference of more than 20 mm Hg. Long-term follow-up is available on 24 of 26 patients with a mean follow-up of 42±24 months (range, 12–88 months). Mean peak systolic pressure difference across the area of coarctation decreased from 40.3±17.4 before angioplasty to 8.5±8.3 mm Hg after final angioplasty (p<0.05) and 7.5±7.5 mm Hg at follow-up. Mean systolic blood pressure in the upper extremities decreased from 133.1±14.9 before angioplasty to 111.1±14.1 mm Hg at long-term follow-up (p<0.05).

Conclusions. Balloon angioplasty should be considered the treatment of choice for relief of recurrent aortic coarctation. (Circulation 1991;84:1150–1156)

Despite ongoing advances in surgical techniques for repair of coarctation of the aorta, the long-term results are not always satisfactory. The incidence of recurrent or residual obstruction is significant (8–54%) and frequently requires repeat surgery.1–8 Surgical management of recurrent or residual aortic coarctation is associated with some morbidity and mortality and an incidence of repeat recoarctation that may be as high as 20%.1,2,9 As angioplasty techniques were refined and larger low-profile balloons were developed, a nonsurgical approach to recoarctation became available. Several reports have documented both the efficacy and safety of this procedure. However, there are little data available on the long-term follow-up of these patients.10–19 This report details the initial results and long-term evaluation of both the relief of obstruction and the presence of hypertension after balloon angioplasty for recurrent coarctation.

Methods

Patient Population
From June 1983 to December 1989, 26 patients underwent 29 balloon angioplasty procedures for recurrent or residual aortic coarctation at Yale-New Haven Medical Center. The indication for angioplasty was a blood pressure difference between the right arm and either leg of 20 mm Hg or more on
clinical follow-up. The 18 boys and 8 girls initially underwent surgical repair for aortic coarctation at ages ranging from 2 days to 12 years (median, 13 days). The surgical techniques included resection with an end-to-end anastomosis in 11 patients, subclavian flap aortoplasty in 11 patients, and patch aortoplasty in four patients. The diagnosis was isolated coarctation with or without a patent ductus arteriosus in 13 patients. The remaining 13 patients had associated cardiac defects.

Aortic balloon angioplasty was performed at ages ranging from 4 months to 29 years (median, 4 years and 9 months). Eight patients were less than 1 year old at the time of angioplasty. The time interval between surgery and angioplasty ranged from 4 months to 23 years (median, 2 years and 7 months). The patients’ weight ranged from 5.4 to 61 kg (mean, 25.4±19.3 kg).

**Angioplasty Protocol**

Each patient underwent a complete cardiac catheterization with systemic heparinization (100 units/kg). The pressure difference across the coarctation was measured by either catheter withdrawal across the coarctation or using two simultaneous pressure measurements in the ascending and descending aortas. Angioplasty was attempted for any peak-to-peak systolic pressure difference of 20 mm Hg or more. Cardiac index was measured using either Fick or thermodilution technique. Biplane angiography was performed in all patients proximal to the area of aortic narrowing with contrast injection in either the ascending aorta or the transverse arch. All patients had a discrete coarctation, and no patient was excluded on the basis of anatomy. The diameters of the aortic isthmus (the largest diameter distal to the last great artery branch from the aortic arch and proximal to the coarctation site), the coarctation, and the largest diameter in the descending aorta distal to the coarctation were measured. The diameter of the dilation balloon chosen for the angioplasty was equal to or slightly less than the largest diameter of the descending aorta distal to the coarctation including the area of poststenotic dilatation. An exchange J guide wire was positioned in the ascending aorta, and the appropriate balloon was advanced over this wire and positioned in the center of the coarctation. The balloon was inflated until the waist disappeared and held for 5–10 seconds. The number of inflations ranged from two to five. If the waist did not disappear with an appropriate sized balloon, the procedure was terminated. This occurred in only one patient. After the angioplasty, hemodynamic and angiographic studies were repeated. All angioplasty procedures were performed in retrograde fashion after percutaneous artery entry, and a single balloon technique was used in all. Since 1986, all balloon catheters were placed in the artery via an arterial sheath rather than directly through the arterial puncture site. Catheters were never advanced through the area of the angioplasty without a guide wire after an attempted dilation. Appropriate sedation and analgesia were used as required by the individual patient.

**Figure 1.** Plots of individual peak systolic pressure differences (top panel) and recoarctation diameters (bottom panel) across area of recoarctation before and immediately after initial angioplasty. Mean peak systolic blood pressure decreased from 40.0±16.8 to 10.3±9.5 mm Hg (p<0.05). Coarctation diameter increased from 5.8±3.5 to 9.0±4.3 mm (p<0.05).

**Statistical Analysis**

Data were evaluated by paired t test for individual paired comparisons and by analysis of variance with replication between surgical groups. To achieve statistical significance, probability was set at 0.05.

**Results**

**Initial Angioplasty**

Data at the time of the initial angioplasty are available for all 26 patients. Mean peak systolic pressure in the ascending aorta did not change significantly after angioplasty (before, 136±21 mm Hg; after, 134±21 mm Hg). Mean peak systolic pressure in the descending aorta increased significantly from 94.7±22.1 to 122.5±23.9 mm Hg (p<0.05). Mean peak systolic pressure difference across the coarctation was 40.0±16.8 mm Hg before angioplasty and 10.3±9.5 mm Hg (p<0.05) after angioplasty (Figure 1). Mean diameter of the aortic lumen at the coarctation site increased from 5.8±3.5 to 9.0±4.3 mm (p<0.05) (Figure 1). Only one patient did not demonstrate a change in pressure difference or coarctation diameter after angioplasty. This patient had undergone an end-to-end anastomosis 10.5 years before angioplasty. Her residual coarctation...
was discrete, the waist did not disappear, and the balloon ruptured. There was nothing unusual about the anatomy or the methodology used. That patient underwent surgery soon after the procedure.

The effect of the surgical technique (end-to-end anastomosis, subclavian flap, or patch aortoplasty) on the decrease in pressure difference or increment in aortic luminal diameter after angioplasty was tested by analysis of variance with replication (Figure 2). There was no difference between the groups. The absolute values of aortic diameter both before and after angioplasty were less in the patients who had a subclavian flap procedure. The only factor identified to account for this was the younger age of these patients both at surgery and at subsequent angioplasty (Table 1). The ratio of balloon diameter to coarctation diameter ranged from 1.33 to 4.00 (mean, 2.67). This ratio and the ratio of balloon diameter to the diameter of the aorta either proximal or distal to the coarctation site did not correlate with the reduction in systolic pressure gradient or increase in the diameter of the coarctation. The cardiac index did not change after angioplasty.

Repeat Angioplasty

Three patients (12%) underwent repeat catheterization and angioplasty for a pressure difference of more than 20 mm Hg observed on follow-up at least 6 months after the initial angioplasty procedure. One patient was a 2-year-old boy weighing 10 kg who had an initial reduction in gradient from 45 to 15 mm Hg. At follow-up catheterization 6 months later, the gradient had increased to 40 mm Hg and was successfully redilated with a larger balloon. A second patient was a 14-year-old who initially had a decrease in gradient from 40 to 15 mm Hg and 15 months later had a measured gradient of 20 mm Hg across a small transverse arch with no obstruction across the coarctation site. Dilatation of the arch achieved no further reduction in the pressure difference. The third patient underwent his first angioplasty at age 4 months with a 6-mm balloon and had a reduction in gradient from 93 to 30 mm Hg. Six months later, the gradient had increased to 60 mm Hg, and repeat angioplasty at that time with a larger (10 mm) balloon resulted in complete elimination of the pressure difference across the coarctation site. This patient underwent repeat cardiac catheterization at age 3.5 years that demonstrated no pressure gradient with a widely patent aorta at the site of the initial coarctation (Figure 3).

Complications

Complications that occurred at the time of angioplasty include a significant aneurysm at the inferior margin of the junction of the descending aorta and the transverse arch that occurred in one patient at the time of the original angioplasty (Figure 4). Follow-up angiography 15 months after the procedure demonstrated no significant change in the size of the aneurysm. The ratio of the balloon diameter to the aortic isthmus diameter was 2.2 in this patient and was the highest ratio encountered in the entire group of patients. One patient with occlusion of the femoral artery has excellent collateral flow; however, the superficial femoral artery remains closed on follow-up. There were no other femoral artery complications encountered. Another patient developed a

![Figure 2: Bar graphs of pressure differences (top panel) and coarctation diameters (bottom panel) before and after angioplasty by type of initial surgical procedure. There was no difference between groups by analysis of variance with replication.](http://circ.ahajournals.org/)

<table>
<thead>
<tr>
<th>Table 1: Clinical Profiles of Patients at Time of Surgery for Coarctation and at Angioplasty for Recurrent Coarctation</th>
</tr>
</thead>
<tbody>
<tr>
<td>At surgery</td>
</tr>
<tr>
<td>Male/female (n)</td>
</tr>
<tr>
<td>18/8</td>
</tr>
<tr>
<td>Median age at surgery</td>
</tr>
<tr>
<td>13 days (2 days to 12 years)</td>
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<tr>
<td>End-to-end anastomosis</td>
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<tr>
<td>(n=11)</td>
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<tr>
<td>2 years (3 days to 10 years)</td>
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<tr>
<td>Patch aortoplasty (n=4)</td>
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<tr>
<td>8.5 years (2 months to 12 years)</td>
</tr>
<tr>
<td>Subclavian flap (n=11)</td>
</tr>
<tr>
<td>7 days (2-14 days)</td>
</tr>
<tr>
<td>Diagnosis (n)</td>
</tr>
<tr>
<td>Simple coarctation with or without patent ductus arteriosus</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>Complex coarctation</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>At initial angioplasty</td>
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<tr>
<td>Median age at angioplasty</td>
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<tr>
<td>4.8 years (4 months to 29 years)</td>
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<tr>
<td>End-to-end anastomosis</td>
</tr>
<tr>
<td>(n=11)</td>
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<tr>
<td>11.9 years (6 months to 29 years)</td>
</tr>
<tr>
<td>Patch aortoplasty (n=4)</td>
</tr>
<tr>
<td>11 years (7 months to 14 years)</td>
</tr>
<tr>
<td>Subclavian flap (n=11)</td>
</tr>
<tr>
<td>2.1 years (4 months to 9 years)</td>
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<tr>
<td>n=26.</td>
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blood pressure of 160/120 mm Hg immediately after complete elimination of a 60 mm Hg gradient. This resolved within 6 hours without therapy.

**Long-term Follow-up**

Long-term follow-up data are available on 24 of 26 patients. One patient died of associated cardiac defects at the time of open heart surgery for a single ventricle and severe subaortic obstruction, and one patient was lost to follow-up. Mean duration of follow-up was 42±24 months (range, 12–88 months). Doppler blood pressure measurements in the right arm and either leg were available on all except two patients in whom Doppler blood flow velocity measurement across the region of aortic repair was used for follow-up. One patient has undergone repeat catheterization, and 13 have had follow-up magnetic resonance imaging studies. Mean peak systolic pressure differences across the area of coarctation decreased from 40.3±17.4 before angioplasty to 8.5±8.3 mm Hg immediately after the patient’s final angioplasty (p<0.05) and at follow-up an average of 42 months later was unchanged at 7.5±7.5 mm Hg (Figure 5). Only two patients were left with a gradient of more than 20 mm Hg. These two patients had hypoplastic transverse arches in addition to a discrete coarctation and required surgery for relief of their arch obstruction. At the time of long-term follow-up,
FIGURE 4. Left panel: Aortogram before angioplasty demonstrating recoarctation with no aneurysm. Middle panel: Aortogram immediately after angioplasty reveals aneurysm at inferior junction of transverse arch and descending aorta (white arrow). Right panel: Aortogram 15 months later demonstrates no significant change in size of aneurysm.

FIGURE 5. Top panel: Mean peak systolic pressure difference across recoarctation site and (bottom panel) individual pressure differences across recoarctation site before and immediately after final angioplasty and at an average follow-up of 42 months. Only two patients had a residual pressure gradient of more than 20 mm Hg. *p<0.05.

the blood pressure in the right arm was available for comparison to the value obtained just before balloon dilation. Mean peak systolic pressure decreased from 133.1±14.9 to 111.1±14.1 mm Hg, with every patient demonstrating some decrease in systolic blood pressure (p<0.05). Only one patient is on chronic antihypertensive therapy.

Discussion

The long-term follow-up of patients after surgery for coarctation of the aorta has demonstrated a significant incidence of recurrent or residual coarctation, especially in patients operated on when less than 1 year old.\textsuperscript{1–8} This is reconfirmed in the present study with a median age of 13 days at the time of surgery in the group of patients who developed recurrent or residual obstruction. At the initial angioplasty procedure, 88\% of patients (23 of 26) had a good result with a residual peak systolic pressure difference of 20 mm Hg or less regardless of the type of initial surgery. This is consistent with the excellent initial results of balloon angioplasty for recoarctation reported in other studies.\textsuperscript{10–19} The absence of any mortality from balloon angioplasty in this study and the low mortality for this procedure reported by other investigators\textsuperscript{10–18} compare favorably with the reported mortality at surgery for recoarctation, which ranges from 7\% to 20\%.\textsuperscript{1,2,9}

There are a variety of recommendations regarding the choice of balloon diameter for coarctation dilation, including the diameter of the descending aorta at the level of the diaphragm, the largest diameter of the aorta distal to the coarctation, and the diameter of the isthmus proximal to the coarctation.\textsuperscript{14,16,19–21} We routinely used the largest diameter
of the aorta distal to the coarctation, including any area of poststenotic dilatation. Like the data demonstrate, we have found this to be safe and effective with a low complication rate that is comparable to that of any of the other recommendations.

Aneurysm formation at the site of the angioplasty has been well documented after balloon dilation for native coarctation, occurring in from 6% to 55%.

Its occurrence after angioplasty for recurrent coarctation has only recently been recognized. The criteria for definitive diagnosis of this complication are not well defined. However, if the diameter of the coarctation site after angioplasty is at least 1.5-fold the diameter of the aorta at the level of the diaphragm, an aneurysm is thought to be present. With this definition, only one patient in the present group would be considered to have developed an aneurysm. The incidence of aneurysm formation subsequent to recoarctation angioplasty compares favorably with the incidence in patients after surgical patch aortoplasty. However, the nature of the aneurysms is different for the two groups. Aneurysms are not present at the time of surgery and are detected only in follow-up. Aneurysms after balloon angioplasty in this group are evident at the time of angioplasty and therefore more easily detected. Cooper et al. report an incidence of 6% for aneurysm formation after balloon dilation for recoarctation with two patients developing an aneurysm in long-term follow-up. The long-term incidence after angioplasty is unknown. In our long-term follow-up protocol, 13 patients have undergone magnetic resonance imaging of the thoracic aorta 7 months to 7 years (mean, 3.1 years) after recoarctation angioplasty. To date, no patient who did not manifest aneurysm formation upon immediate postangioplasty angiography had the late development of aneurysm documented by magnetic resonance imaging, and the one patient who developed a definite aneurysm immediately after angioplasty did not have any progression in the size of the aneurysm.

Other reports of morbidity after balloon angioplasty have included stroke and femoral artery complications. Neurological sequelae are very unusual and can be minimized with proper technique. The femoral artery complications should become less significant as lower-profile balloons become available.

Long-term follow-up is necessary to assess the effectiveness of any new form of therapy. The present report is the longest follow-up available to date and demonstrates no reobstruction at the site of the angioplasty for as long as 7 years after the final procedure. Only two patients had a pressure difference of more than 20 mm Hg at long-term evaluation, and this was thought to be at the level of the transverse arch and not related to the original coarctation site. This absence of any significant restenosis at the site of the original coarctation compares favorably with the restenosis rate after surgery for recoarctation, which has been reported to be as high as 20%. Balloon angioplasty offers an extremely effective means of relieving aortic recoarctation, with a low mortality rate and significant hemodynamic improvement. These results compare favorably with reported surgical results for recurrent or residual coarctation. This can be accomplished without the need for general anesthesia or a repeat thoracotomy, minimizing blood loss and shortening the duration of hospitalization considerably. The potential savings in patient discomfort and monetary expenditures are very significant. Although there is a small risk of aneurysm formation at the time of angioplasty and on medium- to long-term follow-up, this does not appear to be as high as the long-term incidence associated with surgical patch aortoplasty. Whether long-term results with angioplasty will continue to remain this optimistic will require further follow-up.

Balloon angioplasty should be considered the treatment of choice for relief of recurrent aortic coarctation, regardless of whether the original surgical technique involved was an end-to-end anastomosis, subclavian flap, or patch aortoplasty.

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References


KEY WORDS • aneurysms • aortoplasty • coarctation • congenital heart surgery
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