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Balloon Angioplasty of Recurrent Coarctation: A 12-Year Review

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Objectives. **This study was undertaken to investigate the long-term outcome of balloon angioplasty for recurrent coarctation of the aorta in a large series of patients.**

Background. **Balloon angioplasty has become the standard treatment for residual or recurrent aortic coarctation. Despite the widespread use of this treatment modality, there are few data outlining the long-term outcome of a large patient cohort.**

Methods. **Clinical, echocardiographic, hemodynamic and angiographic data on 90 consecutive patients who underwent balloon angioplasty between January 1984 and January 1996 were reviewed.**

Results. **Mean systolic pressure gradients were reduced from 31 ± 21 to 8 ± 9 mm Hg after dilation ($p = 0.0001$). The mean diameter of the stenotic site, measured in the frontal and lateral views, increased by 38% and 35%, respectively ($p = 0.001$). Neurologic events occurred in two patients, with one death. An aortic tear occurred in one patient, requiring surgical intervention. Optimal results were defined as a postprocedure gradient <20 mm Hg and were obtained acutely in 88% of patients. At long-term follow-up (12 years), 53 (72%) of 74 patients with an early optimal result remained free from reintervention. Transverse arch hypoplasia, defined as an arch dimension <2 SD below the mean for age, was the primary predictor of the need for reintervention.**

Conclusions. **Although the majority of patients undergoing percutaneous balloon angioplasty for recoarctation of the aorta will achieve long-term benefit, the need for further surgical intervention in those with transverse arch hypoplasia remains high.**

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Recurrent stenosis after repair of aortic coarctation is not an uncommon clinical occurrence, with an incidence varying from 16% to 60%, reflecting the definition of recurrence and the length of follow-up (1–5). The need for surgical reintervention ranges from <5% to >50% (6). Percutaneous balloon angioplasty to treat such lesions, first described by Singer et al. (7), has been associated with satisfactory early and intermediate-term results (8–27). The long-term impact of angioplasty in this group of patients has not, however, been critically detailed from a large, single cohort (19–23,28–30). The present review examines late follow-up results from a large series of patients who had undergone balloon angioplasty for aortic recoarctation.

Methods

Recurrent aortic arch obstruction was defined as a rest systolic arm to leg blood pressure gradient by sphygmomanometer ≥20 mm Hg (29) and evidence of discrete aortic narrowing at the time of angiography.

Technique of balloon dilation. General anesthesia was used in all procedures. The first five patients in our series had direct insertion of the dilating catheter into the femoral artery after an arterial cutdown because of concerns related to the size of the catheters. These patients developed femoral artery thrombosis and required thrombectomy, despite primary surgical repair at the conclusion of the procedure. This approach was subsequently abandoned in favor of percutaneous access. All patients underwent a hemodynamic study and aortography (1 to 2 ml/kg, Hexabrix [Mallinckrodt Inc.] or Isovue [Squibb Inc.]) in the 20° left anterior oblique and lateral views. Initially, retrograde arterial access allowed placement of an angiographic catheter used for aortography, guide wire placement and balloon insertion. Our current approach is to enter the left heart with a transatrial septal puncture, float a balloon-tipped angiographic catheter (Berman [Critikon Inc.]) into the ascending aorta and obtain an ascending aortogram to detail the anatomy (using the same views described earlier). Subsequently, a retrograde arterial catheter is placed, simultaneous ascending and descending aortic pressures are obtained and angioplasty is performed. The transatrial catheter in the ascending aorta allows continual arterial monitoring during the inflation and repeat aortography to judge the anatomic impact

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of the procedure. This technique avoids arterial exchange, thus lessening trauma to the femoral artery. Patients were routinely given 150 IU/kg body weight heparin sulfate intravenously (maximal dose 5,000 IU) and an additional 75 IU/kg if the study exceeded 2 h. Activated clotting times were not measured.

The balloon diameter was chosen not to exceed 150% of the diameter of the aorta proximal to the stenotic site, with the initial diameter two to three times that of the stenotic segment. An 0.035-in., 260-cm exchange guide wire (Cook Inc.), placed through an end-hole catheter, was curled above the aortic valve and maintained in the ascending aorta throughout the procedure. A Doppler ultrasound probe was taped to the left carotid artery to monitor cerebral blood flow during balloon inflation (31). Balloon position was adjusted if the carotid artery flow signal was compromised during a test inflation. Such adjustments were rarely necessary. After dilation, an intravenous heparin sulfate infusion was started if the pedal pulse was absent 1 h after the procedure, with a bolus of 75 IU/kg and infusion at 20 IU/kg per h, adjusting the activated partial thrombin time between 60 to 100 s. The infusion was maintained for 24 h, and thrombolytic therapy was started if the pulse did not return (32). Written informed consent was obtained from all parents in accordance with the Human Subjects Protection Committee of The Hospital for Sick Children, University of Toronto.

Aortic arch measurements. All cineangiograms were reviewed and the diameters of the following were recorded: ascending aorta, transverse aortic arch (between the brachiocephalic and left common carotid arteries), isthmus (that area beyond the left subclavian artery or, if a subclavian flap had been performed, just proximal to the coarctation site), coarctation site, descending aorta at the level of the diaphragm and isthmus and coarctation site after the angioplasty procedure. All measurements were made at end-systole and corrected for magnification using the known diameter of the angiographic catheter.

Assessment of transverse arch hypoplasia. Transverse arch dimensions, measured between the brachiocephalic and left carotid arteries, were normalized to transverse arch dimensions previously obtained from age-matched control subjects without aortic pathology at our institution (unpublished data). Transverse arch hypoplasia was defined as a transverse arch z-score less than −2.

Follow-up. Patients had 6-month follow-up and then yearly. Blood pressure measurements were performed in the right arm and the noncatheterized leg at hospital discharge and at follow-up. Four patients were lost to follow-up. Clinical and echocardiographic follow-up data were available in 86 patients with a median follow-up time of 39 months (range 3 to 144).

The morphology and dimensions of the thoracic aorta were assessed in follow-up by magnetic resonance imaging in 30 patients and previously reported (33). Imaging was performed in a 1.5-tesla superconducting magnetic scanner, using a spin echo technique with cardiac gating and respiratory compensation. Five-millimeter thick images that included axial, oblique coronal and oblique sagittal planes were obtained with 1-mm interspersing. Measurements of the diameter of the following aortic segments were made: ascending and descending aorta at the level of the carina, transverse aortic arch, isthmus, narrowest segment of the descending aorta, widest segment of the descending aorta and abdominal aorta at the level of the diaphragm. In addition, gradient recalled acquisition scanning of the pelvic vessels was carried out in an axial plane in two patients (33).

Success. Immediate procedural success was defined as a reduction in the pressure gradient across the site of coarctation to <20 mm Hg or an increase in the dimension of the stenotic site to ≥90% of the isthmal diameter in those patients with gradients <20 mm Hg at catheterization (artificially reduced owing to anesthesia). Long-term success was defined as a compound outcome of arm to leg gradient <20 mm Hg by cuff sphygmomanometer and freedom from reintervention.

Data analysis. Patient and procedural characteristics are expressed as frequencies, mean ± SD or median and range. Risk factors for an early suboptimal outcome, defined as a gradient >20 mm Hg by blood pressure cuff sphygmomanometer, were sought using the chi-square test, Student *t* test and Kruskal-Wallis analysis of variance. Risk factors for a long-term suboptimal outcome, defined as a gradient >20 mm Hg and need for reintervention to address the aortic arch, were sought using Cox proportional hazards modeling.

Results

From January 1984 through January 1995, balloon angioplasty was performed 100 times in 90 consecutive patients (53 male, 37 female) who had developed recurrent aortic arch obstruction after attempted surgical repair. A variety of surgical techniques were employed and included subclavian flap aortoplasty (n = 45), end to end anastomosis (n = 31) and patch aortoplasty (n = 14). Although 19 patients had an isolated lesion, others had associated defects, including a bicuspid aortic valve (n = 18), a ventricular septal defect (n = 9), both a bicuspid aortic valve and ventricular septal defect (n = 6), hypoplastic left heart syndrome after stage I Norwood repair (n = 13) and miscellaneous complex lesions (n = 25) (Table 1).

Patients had a median age at dilation of 1.1 years (range 0.1 to 20.0) and a weight of 9 kg (range 2.7 to 81.0). Nine patients had a second dilation 2 to 36 months after initial angioplasty, with one patient having three balloon dilations.

Early results. The systolic pressure gradient across the coarctation site decreased from 31 ± 21 mm Hg to 8 ± 9 mm Hg after balloon angioplasty (p = 0.0001). The ratio of the mean aortic pressures in the ascending to descending aorta decreased from 1.4 ± 0.4 mm Hg to 1.1 ± 0.1 mm Hg (p = 0.0001), and the diameter of the coarctation site increased from 4.4 ± 2.8 mm to 7.3 ± 2.8 mm (p = 0.0001) (Table 2). An immediate successful result was obtained in 79 patients (88%). In the remaining 11 patients (12%), pressure gradients after angioplasty ranged from 20 to 45 mm Hg. Patient and proce-

Table 1. Characteristics of Study Group

Male/female	53/37
Age (yr)	
Median	1.1
Range	0.1–20
Weight (kg)	
Median	9.0
Range	2.7–81
Diagnoses	
Isolated coarctation	19
Bicuspid aortic valve	18
Ventricular septal defect	9
Bicuspid aortic valve and ventricular septal defect	6
Hypoplastic left heart syndrome (after stage I Norwood)	13
Other	25
Type of surgical repair	
Subclavian flap arterioplasty	45
End to end anastomosis	31
Patch aortoplasty	14
Transverse aortic arch z-value	−1.2 ± 1.5
p value	0.0001

Data presented are number of patients or mean value ± SD, unless otherwise indicated.

Table 3. Factors Affecting Early Outcomes

	Optimal Outcome	Suboptimal Outcome*	p Value
Male/female	47/32	6/5	0.75
Age (yr)			
Median	1.5	2.8	0.61
Range	0.1–20	0.2–15	
Weight (kg)			
Median	8.4	12.6	0.57
Range	3.2–81	2.8–60	
Balloon size (mm)	10.9 ± 4.1	10.4 ± 4.0	0.68
Balloon/to coarctation size ratio	3.0 ± 1.2	3.0 ± 1.1	0.91
Transverse arch dimension (mm)	8.8 ± 3.7	8.9 ± 5.0	0.94
Transverse arch to descending aortic dimensions (mm)	0.9 ± 0.3	0.9 ± 0.3	0.77
z-value of transverse arch	1.2 ± 1.4	1.6 ± 1.3	0.41
Preprocedural gradient (mm Hg)	29 ± 21	41 ± 17	0.07
Preprocedural coarctation diameter (mm)	4.4 ± 2.7	4.0 ± 2.3	0.68

*Gradient after dilation >20 mm Hg. Data presented are mean value ± SD or number of patients, unless otherwise indicated.

dural variables, including age at dilation, body weight at dilation, balloon size, coarctation dimension, ratio of balloon size to coarctation dimension, transverse arch dimension and ratio of transverse arch to descending aorta, did not differ significantly between those patients experiencing a successful and those an unsuccessful immediate result (Table 3). Patients with a lower peak systolic pressure gradient (median 22 vs. 42 mm Hg) across the stenotic segment tended to have a higher likelihood of an optimal early result ($p = 0.07$).

Early failures. Of the 11 patients with an unsuccessful initial procedure, 7 had associated complex disease—5 with multiple levels of left-sided obstruction and 2 with postsurgical repair of the interrupted aortic arch. The remaining four patients had an isolated coarctation, all having undergone initial repair with end to end anastomosis.

Early complications. Two patients had neurologic complications. One patient died after the procedure due to cerebral edema secondary to a cerebral infarction. At autopsy, as previously reported (31), an incomplete circle of Willis with an absent posterior communicating artery was identified. Another patient developed transient cortical blindness thought to be embolic. One patient, several years after end to end anastomosis, developed a transmural aortic tear at the time of angioplasty and required urgent operative intervention. A persistently absent femoral artery pulse, 24 h after the procedure, occurred in 22 patients: 10 patients received heparin therapy, 5 received thrombolytic therapy, 6 required surgical thrombectomy (including the original 5 patients who had initial arterial cutdowns) and 1 required a saphenous vein graft. All patients had complete resolution of the thrombosis.

Table 2. Early Hemodynamic and Angioplasty Results*

	Before Procedure	After Procedure
Ascending/descending aortic pressure ratio	1.4 ± 2.8	0.4 ± 0.1
Pressure gradient (mm Hg)	30.0 ± 21.0	7.0 ± .09
Coarctation dimension (mm)	4.4 ± 2.8	7.3 ± 28.0

*$p = 0.001$ for all comparisons. Data presented are mean value ± SD.

Late results. During the follow-up interval of 3 to 144 months (median 39), 4 of the 79 patients with an early optimal result were lost to follow-up; 1 patient died 3 months after dilation (due to an unrelated episode of sepsis); 10 patients had surgical intervention for recurrent recoarctation at the site of balloon dilation a median 18 months (range 2 to 144) after the initial procedure; 2 patients underwent surgical augmentation of the transverse arch in isolation, 46 and 72 months after angioplasty; and 9 patients underwent repeat balloon dilation for recurrent recoarctation of the aorta. Indications for repeat angioplasty included discrete narrowing at the previous angioplasty site. Two of the nine patients had initially undergone successful balloon dilation of a hypoplastic isthmus rather than focal narrowing of the previous coarctation site. Fifty-three (72%) of the 74 patients with an early optimal result remained free from reintervention at follow-up.

Of the 11 patients with an initial failed result (gradient >20 mm Hg), 8 underwent surgical intervention at a median 2 months (range 1 day to 30 months after angioplasty), 1 had a repeat balloon angioplasty and 2 were managed conservatively with a subsequent reduction in gradient to <20 mm Hg at follow-up.

Repeat angioplasty. Nine patients underwent repeat balloon angioplasty 2 to 36 months after the initial procedure, with a reduction in pressure gradient from 27 ± 15 mm Hg to 12 ± 8 mm Hg ($p = 0.004$). Coarctation dimensions increased to 5.5 ± 0.7 mm ($p = 0.0001$). A successful immediate result (gradient <20 mm Hg) was achieved in eight of the nine

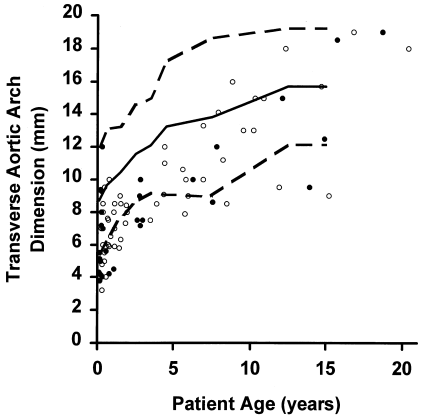

Figure 1. Mean (**solid curve**) (±2 SD [**dashed curves**]) transverse arch dimensions for children of different ages without aortic arch pathology. **Solid circles** = patients with long-term failure of balloon angioplasty; **open circles** = patients with long-term success of balloon angioplasty.

Table 4. Predictors of Time to Reintervention

	Relative Odds of Reintervention (95% CI)	p Value
z-value of transverse aortic arch <2 SD	2.34 (1.06–5.16)	0.04
Preprocedure		
Ascending/descending aortic gradient (per 10-mm Hg increment)	1.30 (1.12–1.52)	0.0007
Pressure ratio (per 0.1 increment)	1.17 (1.08–1.27)	0.0002
Postprocedure		
Ascending to descending aortic gradient (per 10-mm Hg increment)	2.08 (1.49–2.09)	0.0001
Pressure ratio (per 0.1 increment)	1.34 (1.12–1.59)	0.001
Change in ascending to descending aortic pressure ratio (per 0.1 increment)	0.87 (0.79–0.95)	0.003
Change in coarctation diameter (per 1-mm increment)	0.76 (0.57–1.01)	0.060

CI = confidence interval.

patients. Long-term failure of the second angioplasty occurred in five (62%) of the nine patients, with four patients requiring surgical intervention and one repeat balloon angioplasty (24 months after angioplasty). No complications occurred at repeat angioplasty.

Late complications. One patient was found to have an aneurysm of the coarctation site on magnetic resonance imaging, which required surgical repair. Of the 12 patients who underwent magnetic resonance imaging of the pelvic vessels, the external iliac and common femoral artery were stenotic in four patients (33).

Transverse arch hypoplasia. Thirty-two patients had transverse arch hypoplasia (Fig. 1). There were no significant differences in absolute transverse arch dimensions before dilation (Table 3), transverse arch to descending aorta ratios or z-values of the transverse arch between those patients with successful and those with unsuccessful early results (Table 3). Fifty-three percent of patients with transverse arch hypoplasia had a suboptimal long-term outcome requiring reintervention on the aortic arch, whereas only 29% of patients without transverse arch hypoplasia had an unsuccessful long-term result (p = 0.04) (Fig. 2).

Additional factors affecting long-term outcome. There was no relation between time to reintervention and type of initial surgical procedure. In addition, no relation was found between time to reintervention and the following variables: age at balloon angioplasty, weight at angioplasty, percent increase in coarctation diameter, balloon to coarctation site ratio, balloon to transverse arch ratio and absolute difference in pressure gradient.

Predictors of time to reintervention, in addition to a transverse arch z-value less than −2, included a higher preangioplasty pressure gradient and a higher pressure gradient immediately after angioplasty (p = 0.0001) (Table 4). A subanalysis of the 32 patients with transverse arch hypoplasia revealed no association between long-term outcome and percent increase in coarctation dimension (p = 0.56), age at angioplasty (p = 0.23), balloon to coarctation ratio (p = 0.76), balloon to aortic arch ratio (p = 09.59) and ratio of transverse arch dimension to descending aorta (p = 0.34).

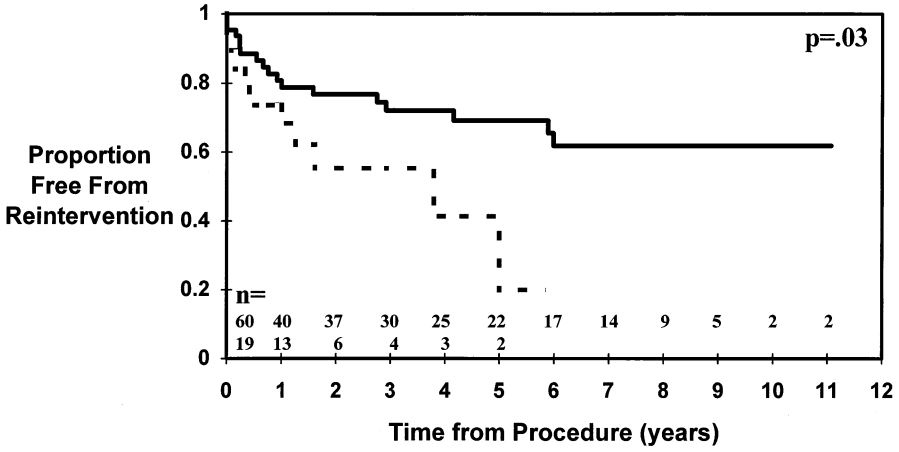

Figure 2. Kaplan-Meier estimates of freedom from reintervention for patients with and without transverse arch hypoplasia after initial dilation. **Solid line** = patients without aortic arch hypoplasia; **dashed line** = patients with transverse arch hypoplasia.

Discussion

Despite the frequent use of balloon angioplasty for treatment of aortic recoarctation, there are few reports detailing the procedure's long-term effectiveness (30). This review represents a unique, large cohort from a single center, encompassing a period of over one decade, and addresses clinical issues impacting long-term outcomes.

Immediate outcome. Successful relief of recurrent aortic obstruction, as evidenced by a residual gradient <20 mm Hg, occurred in 88% of patients, and thus reaffirms that aortic balloon angioplasty provides excellent relief of obstruction with low morbidity and mortality. Our immediate results are comparable with those reported by other investigators (22–28), as well as with the reported incidence of recoarctation (7% to 30%) after repeat surgical repair (34,35). Of the patients with initial failed results, the majority had a recurrent coarctation in the setting of complex multilevel left-sided obstruction. These patients may be less amenable to balloon dilation because of persistence of abnormal flow patterns within the aortic arch, negatively affecting vessel remolding. Of those patients with isolated coarctation, immediate failure was only noted in those having previously undergone end to end anastomosis. This may be related to the form of repair (extended reconstruction), which may result in a site of obstruction being more proximal on the transverse arch.

Long-term outcome. The present report is the longest follow-up study to date. Although other investigators have reported excellent long-term results with no late failure in those patients with an initial successful result (19,21), such studies have involved small patient cohorts and shorter follow-up periods. Reintervention was required (repeat angioplasty or surgical repair) for recurrent aortic arch narrowing in 33% of our patients over an interval of up to 12 years. The higher incidence of reintervention in our study group may reflect both the longer follow-up duration and a more liberal definition of failure.

Complications. The operative mortality for repair of recoarctation has been reported to be as high as 7% (1,26,34–37), whereas the mortality rate for balloon angioplasty has been 2.5% (19,20). Cerebrovascular accidents are a reported complication of balloon angioplasty of recoarctation (37). In the present study, one patient died due to cerebral infarction secondary to insufficient blood flow caused by temporary occlusion of the left carotid artery during dilation, in association with a hypoplastic communicating artery in the circle of Willis (31). As part of the procedure, monitoring of the blood flow in the left carotid artery during dilation may help prevent this event. Both surgical repair and balloon angioplasty are associated with a low risk of aortic aneurysms (38–42). We found no aneurysms at angiography immediately after dilation, although follow-up revealed a focal bulge at the coarctation dilation site in one patient. Femoral artery thrombosis is a common complication of this and other interventional procedures using arterial vascular access. In this study, 25% of patients required treatment for femoral artery thrombosis, and 37% of patients <1 year of age required heparin or thrombolytic therapy. Thrombus resolution was nearly uniform in all our patients. The higher incidence of arterial complications in infants is in agreement with the findings of others (27,41).

Transverse arch hypoplasia. The presence of transverse arch hypoplasia, defined as a transverse arch z-value less than −2, was the greatest predictor of a suboptimal long-term outcome (Table 4). In contrast to previous studies that have defined transverse arch hypoplasia by arbitrary reference to other aortic arch dimensions (23), this study compared transverse arch dimensions in patients undergoing balloon angioplasty with arch dimensions in age-matched control subjects without aortic arch pathology. Despite successful initial relief of restenosis in the majority of these patients, there was subsequently a greater need for reintervention to address narrowing of the aortic arch. Although the majority of such patients had discrete aortic narrowing at the time of repeat operation, the hemodynamic significance of such an obstruction is hard to ascertain in the presence of aortic arch hypoplasia. Balloon angioplasty in these patients may provide temporary relief of significant obstruction, allowing the patient to attain a more optimal weight for arch reconstruction.

Conclusions. Percutaneous balloon angioplasty for recoarctation of the aorta is immediately effective in reducing pressure gradients. Although the majority of patients with normal transverse arch dimensions will achieve long-term benefit, those patients with a transverse arch dimension <2 SD below that predicted for age have a high likelihood of requiring repeat intervention.

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