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Recurrent Coarctation: Is Surgical Repair of Recurrent Coarctation of the Aorta Safe and Effective?

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Background. Persistence or recurrence of stenosis is a complication of coarctation repair and is associated with major long-term morbidity. The rate of recurrence varies significantly, depending on the age of the patient, technique at initial repair, and the arch anatomy. We reviewed our experience with surgical repair of recurrent coarctation of the aorta and compared it with our institutional experience with balloon aortoplasty.

Methods. We retrospectively reviewed our experience with 1,012 patients undergoing initial repair of coarctation between 1960 and 2008. During that time, 103 patients (10%) required reintervention. Median age at reintervention was 6.5 years (range, 2 weeks to 44 years) and median weight was 12 kg (range, 1.9 to 94 kg). Fifty-nine patients with recoarctation had surgical repair, and 44 patients were treated with balloon aortoplasty with or without stent placement.

Results. Ninety-five percent of patients have been followed up (median time, 14.2 years; range, 2 months to 42 years). There were 5 late deaths. Actuarial survival was 98% at 15 and 40 years in patients with surgical reintervention, and it was 91% ($p = 0.001$) at 15 years in patients with balloon aortoplasty reintervention. A second redo coarctation of the aorta reintervention was performed in

12 patients: 8 patients after percutaneous intervention (nonsurgical) and 4 patients after surgical recoarctation repair. The median interval between first and second reintervention was 3.5 years (range, 1 month to 14 years). One patient who had two dilations underwent a third and fourth reintervention: patch enlargement and pseudoaneurysm resection. Freedom from reintervention in the surgical group was 96% at 15 years and 94% at 40 years, which was compared with actuarial freedom from reintervention for patients with percutaneous intervention (balloon/stent) at 15 years (82%; $p < 0.001$).

Conclusions. Our study demonstrates that surgical repair of recurrent coarctation of the aorta can be performed safely and with excellent results. The recurrence after surgical reintervention is low, and most patients to date have not required further intervention. Balloon aortoplasty as an alternative method of managing recoarctation is efficient and less invasive than surgery; however, well-described complications may occur. Recurrence rates with angioplasty are significantly higher than with surgery.

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Coarctation of the aorta (CoA) is the fifth most common cardiovascular anomaly requiring surgical intervention in infants and children. The incidence of CoA is 4 in 10,000 live births, accounting for 5% to 8% of children with congenital heart disease [1]. The natural history of this congenital disorder, through progressive hypertension, leads to heart failure and premature death

[2]. Without correction, the mean life expectancy of patients with aortic coarctation is 35 years, and 90% die before reaching age 50 years of age [3]. As the disease progresses, various vascular complications can occur, such as coronary disease, aortic dissection and rupture, hemorrhagic cerebrovascular accident, or bacterial endocarditis [3, 5–8].

Since surgical repair of CoA became available in 1944 [4], great progress has been made in the diagnosis and treatment of CoA. Perioperative morbidity and mortality have been greatly reduced, particularly in cases of uncomplicated CoA not associated with complex congenital heart disease [5–8].

Persistent arterial hypertension after repair is performed at an older age, and recurrence of CoA in repairs

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done in neonates, however, continues to challenge our management strategies [5, 6]. Postoperative hypertension, which occurs in 7% to 33% of patients, may be a result of recurrent or residual CoA or may be idiopathic [8, 9]. The incidence of postoperative recurrent CoA ranges from 5% to 50%, depending on the criteria and methods used in making the diagnosis [9]. The rate of recurrence varies significantly, depending on the age at initial repair [9, 10]. The specific surgical method of repair, suture material used, and sewing technique do not appear to be as important as once suggested in determining recurrence [9].

Balloon aortoplasty with or without stent placement of CoA has been introduced in the last several years as an alternative method of managing aortic coarctation, particularly recurrent CoA. This is certainly a less invasive method of intervention, although well-described complications may occur and recurrence rates are relatively high (more than 50% for primary treatment in infants) [11-13]. The role of balloon aortoplasty and stent placement for recurrent CoA needs to be further defined. We report our experience with the management of aortic recoarctation treated by balloon aortoplasty/stent placement or repeat surgery and report the outcomes of both approaches at our institution.

Material and Methods

This study was approved by the Institutional Review Board at Indiana University. The need for individual consent was waived.

Study Subjects

Between January 1960 and January 2008, 1,012 patients with isolated CoA or with complex coarctation, or both, underwent repair at the James Whitcomb Riley Hospital for Children in Indianapolis, Indiana. There were 648 males (64%) and 364 females (36%). Diagnosis included isolated CoA in 506 of 1,012 patients (50%), CoA and ventricular septal defect (VSD) in 213 (21%), and CoA with complex intracardiac anomalies (complex coarctation) in 293 (29%). The distributions of associated cardiovascular anomalies and noncardiac syndromes are shown in Table 1. Associated isthmus hypoplasia was defined as an isthmus diameter of less than 40% of the diameter of the ascending aorta [14]. Arch hypoplasia

Table 1. Associated Cardiovascular Anomalies and Noncardiac Syndromes

	Number of Patients (%)
Isolated coarctation	506 (50%)
Coarctation with ventricular septal defect	213 (21%)
Coarctation with complex anomaly	293 (29%)
Aortic stenosis	132
Single ventricle	65
Atrioventricular septal defect	32
Mitral valve anomaly	29
Transposition of the great arteries	29
Double-outlet right ventricle	6
Noncardiac anomaly syndromes ^a	202 (20%)

^a Syndromes included Turner, Down, DiGeorge, Shone, Williams-Beuren, von Willebrand, Marfan, Dandy-Walker, pyloric stenosis, diaphragmatic hernia, bronchopulmonary dysplasia, Noonan, Russell-Silver, Hirschprung, Goldenhar, horseshoe kidney, Bad-Chiari, Edwards, Rubinstein-Taybi, Holt-Oram, VATER, and CHARGE.

was defined as a proximal or distal transverse arch diameter of less than 50% of the diameter of the ascending aorta [14]. Isthmus hypoplasia or arch hypoplasia, or both, was initially present in 314 (31%) of our 1,012 patients. Bicuspid aortic valve was present in 587 patients (58%), and congenital syndromes (Turner, Down, and so forth; all syndromes are given in Table 1) were present in 202 patients (20%).

The median age at first operation for the entire series was 2.5 months (range, 2 days to 44 years). The median age at first operation was 3.2 months (range, 4 days to 44 years) in patients having isolated CoA; and it was 26 days (range, 2 days to 4 years) in patients with CoA and VSD, and 16 days (range, 2 days to 2 months) in patients with complex CoA. Four hundred forty-eight patients (45%) were aged 1 month or less, 105 (10%) were aged 1 month to 3 months, 102 (10%) were aged 3 months to 1 year, 338 (33%) were from 1 year to 18 years, and 19 were adult patients (2%) at the first intervention. The median age, number of patients at initial surgery, number of early deaths, and number of reinterventions according to type of repair is shown in Table 2.

There were 32 early deaths (3%) and 45 late deaths (5%) after initial CoA repair (Fig 1). Overall survival estimated by the Kaplan-Meier method, which included early mor-

Table 2. Median Ages, Number of Patients at Initial Surgery, Number of Early Deaths, and Reinterventions According to Type of Surgery

Procedure	Initial No. of Patients	Median Age	Early Deaths No. of Patients	Redo No. of Patients
Resection and end-to-end anastomosis	473	3 months	17 (4%)	50 (11%)
Subclavian flap angioplasty	264	3 weeks	9 (3%)	20 (8%)
Prosthetic patch angioplasty	216	7 years	5 (2%)	26 (12%)
Combination of end-to-end and subclavian flap techniques	42	2 weeks	1 (2%)	3 (7%)
Tube graft	10	14 years	0	3 (30%)
Unknown (unspecified)	7	4 years	0	1 (14%)
Total	1,012	2.5 months	32 (3%)	103 (10%)

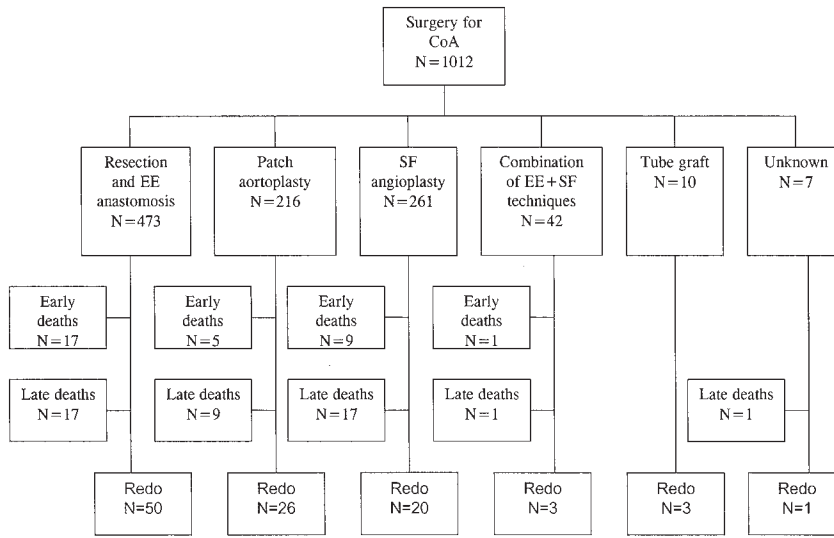


Fig 1. Diagram of all patients undergoing primary repair of coarctation of the aorta (CoA) over a 45-year period (n = 1,012). (EE = end-to-end; SF = subclavian flap.)

tality in all patients, was 96% at 1 year, 94% at 10 and 20 years, and 92% at 30 and 45 years. The group of patients with complex associated anomalies had a freedom from mortality of 86% at 45 years as compared with a freedom from mortality of 95% at 45 years for simple CoA and CoA with VSD ($p = 0.001$). The numbers of early deaths according type of surgery is shown in Table 2.

Overall actuarial freedom from reoperation (entire CoA group) was 99% at 1 year, 98% at 10 years, 94% at 20 and 30 years, and 90% at 45 years. There is no a difference in the incidence of re-CoA between group of patients with complex associated anomalies and simple CoA or CoA with VSD at 45 years (88% and 91%, respectively). Among the survivors, 103 patients (10%) underwent re-CoA repair and form the basis of this study.

Data Acquisition

A retrospective review of medical records was performed with regard to initial cardiac diagnosis, pathophysiologic findings, surgical treatment, and hospital mortality. Data from outpatient visits and from patients who died after hospital discharge were obtained from physician, hospital records, or death certificates. Medical records and clinical charts were reviewed for all CoA patients and included

operative records as well as preoperative and postoperative catheterization and echocardiography data. Data collected from the operative admission included diagnosis, previous operative procedures, age, sex, and weight at operation. Patient follow-up data were obtained from hospital and clinic visit records, and were retrieved retrospectively from electronic chart review.

After the initial CoA repair, the patients routinely returned to the clinic for measurement of resting blood pressures and echocardiograms. Resting arm-leg gradients were also obtained and were considered abnormal if greater than 20 mm Hg. Exercise arm-leg gradients were also obtained in some patients and, if more than 40 mm Hg, were likewise considered abnormal. The patients who had persistent hypertension, elevated arm-leg gradients, or significant pressure gradients on echocardiogram (more than 30 mm Hg, or more than 20 mm Hg in case of inadequate collaterals) underwent echocardiography or catheterization, or both. The patients with re-CoA were sometimes discussed with cardiothoracic surgeons before a decision regarding the type of reintervention was made. At other times, the interventional cardiologists proceeded with balloon dilation and stenting if they felt it was feasible and did not discuss it with surgeons.

Postintervention aneurysm formation was defined according to the criteria of Beekman and coworkers [15]. These included either a fusiform dilation at the CoA site with a diameter greater than 150% of the aortic diameter at the diaphragm or a discrete saccular dilation that was not present at the preangioplasty imaging study. If an aneurysm was detected on a follow-up aortogram, the preintervention aortogram was reviewed to ascertain if this irregularity of the aorta was present before treatment.

Surgical Technique

The surgical technique for both primary and reoperative re-CoA treatment has been described previously [8].

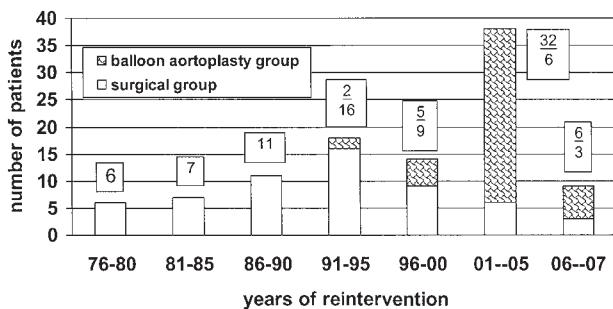


Fig 2. Numbers and time of surgical reintervention (open bars) or balloon aortoplasty reintervention (patterned bars) in patients with redo recoarctation.

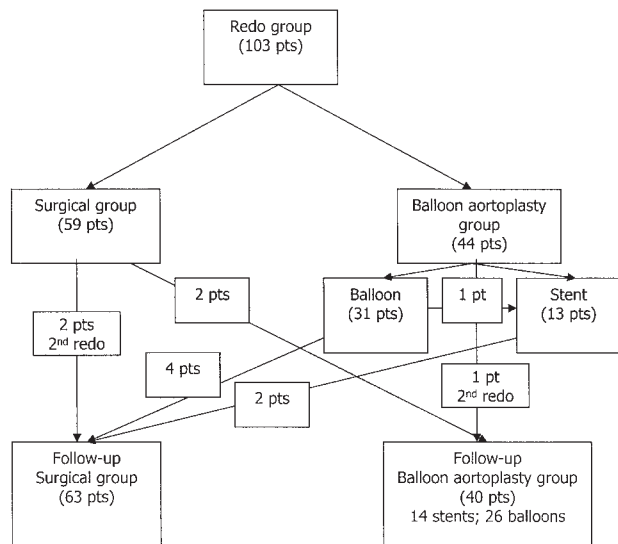


Fig 3. Follow-up information of patients (pts) with redo coarctation of the aorta who underwent surgical or balloon aortoplasty reintervention.

Before 1993, all patients presenting with re-CoA underwent redo surgery. More recently, balloon aortoplasty and stent insertion were introduced; some recurrences are preferentially managed by means of transcatheter balloon aortoplasty or stent insertion (Fig 2).

In patients who underwent redo operations, the surgical approach was dictated by aortic arch anatomy. Patients having a normal arch or a moderately hypoplastic distal arch were operated on through a left thoracotomy, and the intraoperative management was much the same as that for initial CoA repair. Circulatory support during reoperation was used only in patients who had post-CoA aneurysms, inadequate collateral, or abnormal somatosensory evoked potential changes during test clamping of the aorta. Circulatory support was established between the left atrium (or inferior pulmonary vein) and the descending aorta (left heart bypass) in this group. Patients with a residual or persistent hypoplastic proximal or transverse aortic arch (n = 3), associated or not with a recurrent coarctation were approached through a median sternotomy. In these patients, deep hypothermia and circulatory arrest were utilized. Under circulatory arrest, the aortic arch was incised along its concavity starting below the innominate artery and carried through and then 1 to 2 cm beyond the re-CoA area. The back flow from the descending aorta was controlled with suckers, and an open approach with patch enlargement of the aorta was performed with polytetrafluoroethylene (PTFE [W. L. Gore & Assoc, Newark, DE]) or a Hemashield patch (Boston Scientific, Natick, MA).

A number of surgical techniques were employed in the 59 patients who underwent surgical revision (Fig 3): incision of the restricted area and patch enlargement with PTFE or Hemashield was performed in 43 patients, 7 patients had tube graft (PTFE) interposition, 2 patients had subclavian flap angioplasty, and 1 had an extended

end-to-end repair. Of the 6 patients with aneurysm/pseudoaneurysm formation, 2 underwent pseudoaneurysm resection and patch repair, and 4 patients underwent aneurysm resection and tube graft interposition. Of the 44 patients who had first nonsurgical repair, balloon aortoplasty alone was employed in 31, and 13 had concomitant stent placement (Fig 3).

Statistical Analysis

The SPSS statistical program for Windows version 10 (SPSS, Chicago, IL) was used to perform data analysis. Data are expressed as mean ± SD and range. The Kaplan-Meier product limit method and Cox proportional hazards regression methods were used for actuarial survival analysis and analysis of freedom from reoperation. Potential risk factors in these analyses included sex, age (less than 1 month, 1 month to 1 year, 1 year to 18 years, more than 18 years), type of surgery, era (before 1980, 1981 to 1990, after 1990), isolated versus complex intracardiac anomalies, associated aortic anomalies (aortic arch hypoplasia, isthmus hypoplasia, transverse hypoplasia, bicuspid aortic valve, aortic stenosis), associated intracardiac anomalies (single ventricle, atrioventricular septal defect, mitral valve anomaly, transposition of the great arteries, double-outlet right ventricle), and noncardiac anomaly syndromes. Any p values of 0.05 or less were considered significant. Early mortality was defined as death in the hospital or within 30 days of discharge.

Results

One hundred and three patients have presented with recurrent or persistent CoA after an initial repair. There were 54 boys and 49 girls. Median age at reintervention was 6.5 years (range, 2 weeks to 44 years), and median weight was 12 kg (range, 1.9 to 94 kg). Details concerning their initial aortic repair techniques are outlined in Table 2. Median age at primary repair was 27 days (range, 3 days to 20 years), and median interval from primary repair to reintervention for recurrent aortic obstruction was 4.8 years (mean, 7.2 ± 7.9; range, 1 week to 33 years). At the time of referral for redo surgery, significant arm-to-leg peak pressure gradients were present in all patients and were 48.5 ± 24.8 mm Hg (range, 30 to 120 mm Hg).

A total of 117 reinterventions were required for re-CoA

Table 3. Postprocedural Complication for Recoarctation Intervention

Complication	Surgery (n = 65)	Balloon Aortoplasty (n = 44)
Death	0	0
Neurologic	0	0
Aneurysm formation	0	2
Stent migration	0	1
Surgical reintervention	2	6
Balloon reintervention	2	1
Hypertension at last follow-up	0	5

repair in 103 patients, including surgical treatment (n = 69), transcatheter balloon angioplasty (n = 44), and stent placement (n = 14). Among these patients, 91 had one reintervention, 11 had two reinterventions, and 1 patient had four reinterventions. The most common indication for the first re-CoA repair was recurrent aortic obstruction at the site of previous CoA repair, which was present in 94 (91%) of the re-CoA patients. A less-frequent primary indication for re-CoA repair was aneurysm formation, which occurred in 9 patients (9%). Seven aneurysms occurred after the initial patch aortoplasty, coarctation repair, and 2 occurred after reintervention balloon aortoplasty and stent placement (Table 3). The median time interval between primary CoA repair and redo surgery was 7.5 years (range, 1 week to 33 years), and the median age at reoperation was 9 years (range, 2 weeks to 44 years). The median time between initial CoA repair and balloon aortoplasty was 1 year (mean, 5.4 ± 6.3; range, 2 weeks to 15 years). Twenty-six patients (26 of 44; 60%) had their reintervention during the first year after the initial CoA surgery. The median age at balloon aortoplasty reintervention was 2 years (range, 2 months to 22 years). The option to return to the operating room for surgical repair of the recurrence after 1993, when balloon aortoplasty was available, was based on the anatomic location, severity of the recurrence, and age of the patient. As a general rule, the younger the patient, the more severe and proximal the obstruction, the more likely the patient was referred for surgical reintervention.

Follow-Up

The length of follow-up in patients with recurrent CoA ranged from 2 months to 42 years (median, 14.2 years) and was available for 95% of patients (98 of 103). Follow-up ranged from 2 months to 42 years (median, 25 years) for the 59 patients who underwent a surgical revision of their coarctation repair site and from 6 months to 15 years (median, 5 years) for the 44 patients who underwent balloon aortoplasty with or without stent placement of their recurrence. Follow-up of all reintervention patients is summarized in Figure 3 and demonstrates the late crossover from balloon aortoplasty to surgery and vice versa. All surviving patients are in New York Heart Association (NYHA) functional class I or II at latest follow-up.

Patient Survival

There were no intraoperative deaths after surgical reintervention. There was 1 late death of unknown cause (2%; 1 of 59) 2 years after re-CoA surgery in a patient with a single ventricle. There were no early deaths among the 44 patients who had balloon aortoplasty or stent placement, but there were 4 late deaths (9%; 4 of 44) from 6 months to 3 years (mean, 1.4 ± 1.2 years) after aortic balloon aortoplasty (Table 3). All late deaths were unrelated to balloon reintervention. Two deaths were in patients with single-ventricle physiology in whom heart failure developed. One patient with Shone's anomaly underwent mitral valve replacement 2 years after angioplasty and died 1 year after mitral valve replacement. The last late death was of a patient who underwent balloon aorto-

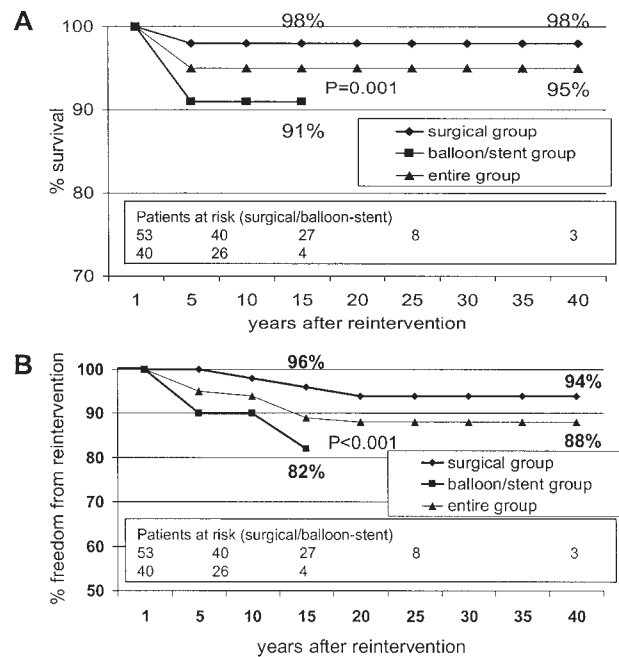


Fig 4. (A) Kaplan-Meier survival curve and (B) freedom from reintervention curve for patients with redo coarctation of the aorta (CoA) who underwent surgical or balloon aortoplasty reintervention. (Diamonds = surgical group; squares = balloon/stent group; triangles = entire group.)

plasty of the recoarctation site and died 9 months later of multiorgan failure when he had VSD closure and pulmonary artery patch arterioplasty.

Overall survival estimated by the Kaplan-Meier method was 97% at 1 year, and 95% at 5, 10, 15, 20, and 40 years (Fig 4A). Actuarial survival was 98% at 5, 15, and 40 years among patients with surgical reintervention, and 91% at 15 years among patients with balloon aortoplasty reintervention ($p = 0.001$). Univariate and multivariate analyses showed that the presence of complex intracardiac anomalies ($p < 0.001$) and age less than 1 year ($p < 0.003$) were significant predictors of mortality after re-CoA repair.

Reintervention

A second redo CoA reintervention was performed in 12 patients: 8 patients after percutaneous intervention (non-surgical) and 4 patients after surgical re-CoA repair (Table 3 and Fig 3). The median interval between first and second reintervention was 3.5 years (range, 1 month to 14 years). One patient, who had two dilations, underwent a third and fourth reintervention; namely, patch enlargement and pseudoaneurysm resection.

Indications for second reintervention were residual obstruction at the site of previous CoA and re-CoA repair (n = 9), migration of a stent over the orifice of an aberrant right subclavian artery (n = 1), aneurysm of distal aortic arch involving the origin of the left subclavian artery (n = 1), and resection and graft replacement of an infected pseudoaneurysm at the site of stent placement (n = 1).

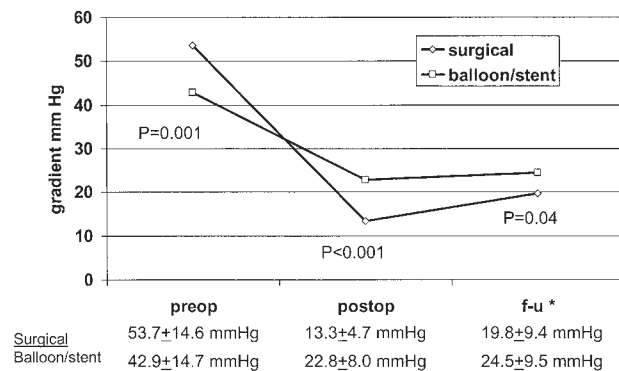


Fig 5. Comparison of preoperative (preop), postoperative (postop), and follow-up (f-u) gradients after surgical (triangles) and balloon aortoplasty (squares) for recurrent coarctation of the aorta (CoA). *Follow-up for patients with surgical re-CoA treatment is 40 years; follow-up for patients with balloon/stent is 15 years.

The overall freedom from re-CoA reintervention, as estimated by the Kaplan-Meier method, was 94% at 10 years, 89% at 15 years, and 88% at 20 and 40 years (Fig 4B). Freedom from reintervention in the surgical group was 96% at 15 years and 94% at 40 years as compared with the actuarial freedom from reintervention for patients with percutaneous intervention (balloon/stent) at 15 years of (82%; $p < 0.001$).

Echocardiographic Gradients

The peak gradients across the coarctation site (preinterventional, postinterventional, and at last follow-up) for the surgical and balloon aortoplasty groups are shown in Figure 5. Fifteen patients had a peak gradient of more than 30 mm Hg at last follow-up (4 patients after surgical treatment and 11 patients after balloon/stent group). Three of them (surgical group) have been treated with reintervention: 1 patient with graft insertion underwent patch enlargement, and 2 patients with patch enlargement underwent balloon aortoplasty and stent insertion (Table 3); 1 remaining patient is awaiting reintervention. In the balloon/stent group of patients, 8 have been treated with a second reintervention (six surgical procedures and two additional balloon aortoplasty), and 3 other patients are awaiting reintervention (Fig 3).

Comment

During the past 45 years, 103 patients presented with recurrent CoA after a primary repair. As in other centers [5, 7], the recurrent rate represents 10% of the patient population treated with surgery. Risk factors for this complication are initial repair at less than 1 month of age and the size and anatomy of the transverse arch [6, 9, 10, 16]. Dodge-Khatami and colleagues [6], in a 40-year meta-analysis review, showed that simple end-to-end anastomosis and subclavian flap repair had the highest incidence of recoarctation, especially when associated with aortic arch hypoplasia. Tube graft insertion in children had the highest incidence of re-CoA (30%), but

patients with patch aortoplasty and end-to-end anastomosis also had high incidences of recurrences (12% and 11%, respectively).

Aortic recoarctation was diagnosed in our study when, after the initial discharge of a patient who had undergone CoA repair with a good result developed a resting arm-leg blood pressure gradient of 20 mm Hg or greater or who had a significant Doppler echocardiographic gradient. Reintervention was elected when signs of systemic hypertension were present or when echocardiography demonstrated hypertrophy or a dilated left ventricle. A small group underwent reintervention if there was an aneurysm at the original repair site.

The primary objective of this study was to compare the outcome of surgical intervention to the more recently introduced technique of balloon aortoplasty with or without stent placement. Balloon aortoplasty is efficient, less invasive, and can treat recoarctation at a lower initial cost and shorter hospital stay. Balloon aortoplasty became the first option of treatment for re-CoA at our institution after 1993, as shown in Figure 1. Very little has been published comparing the outcomes of these two approaches. We undertook this retrospective analysis of these two approaches to see if there was a difference in outcomes. Zoghbi and associates [5] has recently reported a large series of 97 patients with re-CoA intervention and found that balloon aortoplasty had more frequent major complications and a higher recurrence rate. Our analysis supports their conclusions, and is shown in Figure 5 and Table 3. Major complications were three to four times as frequent with balloon aortoplasty as they were with surgery in the Zoghbi study [5] and in our review (Table 3).

Careful preoperative investigations including angiography, magnetic resonance image scanning, and echocardiography may be necessary to allow the best choice of appropriate reintervention therapy. If the site of aortic obstruction is proximal to the CoA repair site and if the transverse aortic arch remains significantly hypoplastic, the lesion is preferentially approached through a median sternotomy. If the recurrent obstruction is just proximal, at or distal to the left subclavian artery, the lesion may best be approached through a redo left thoracotomy.

It is interesting that of the 314 patients (31%) who presented with isthmus or transverse aortic arch hypoplasia at initial coarctation presentation, only 3 patients have required subsequent transverse arch patch augmentation to date. This lack of the need to treat transverse arch hypoplasia demonstrates that the transverse arch will grow in most young infants if the isthmus and coarctation are adequately treated at initial presentation.

When comparing surgical intervention and balloon aortoplasty, results do not show any statistical difference in early and late mortality between the two methods. Conversely, analysis of early and late morbidity seems to demonstrate that surgical repair is safer, more effective, and has a lower incidence of persistent obstruction, and this trend has been demonstrated by others [7]. In particular, no neurologic complications such as spinal cord ischemia, phrenic nerve injury, or recurrent nerve paral-

ysis were encountered in our series and in another surgical series [17] when descending aorta perfusion or hypothermia were utilized. Morbidity after balloon aortoplasty is not infrequent. The most frequent complication reported after balloon aortoplasty are cerebrovascular accidents and femoral artery injuries [18]. Neither of these complications was observed in our study.

Although the present data seem to favor redo surgery in most patients with recurrent aortic obstruction, some authors prefer intravascular stents in their older patients for this indication and have shown good short-term results [19, 20], but long-term outcome is unknown. Aneurysm formation has varied from 0% to 14% and emphasizes the need for long-term follow-up. Other complications of stent implantation after re-coarctation have included femoral artery trauma, neurologic damage, postcoarctation syndrome, and stent migration [12, 13, 18, 21].

Although no patient in our aortoplasty series required surgery for femoral artery trauma, the loss of a femoral pulse was not routinely recorded. Two patients (4.2%) of the aortoplasty group and 14% of the 14 stented patients had aneurysms at the site of stent placement. In 1, the aneurysm was acutely infected and had a contained rupture and required emergent surgery. One patient had stent migration over the subclavian artery, and 6 patients required surgery for incomplete relief of their gradients (Table 3 and Fig 3).

Aortic aneurysms develop in as many as 14% of patients after balloon aortoplasty in some series and are less frequent after surgical reintervention. Aneurysm formation after primary patch aortoplasty has been reported extensively, with the reported incidence varying between 2% and 51% [14, 22]. The cause of aneurysm formation after patch aortoplasty has been attributed to several different factors: patch material, resection of CoA ridge, age, and aortic arch hypoplasia [14, 22–26]. Aneurysm formation was encountered in 9 of our patients (1%) of 980 surviving primary CoA repair, 7 of 211 (3.3%) after initial patch aortoplasty, and 2 of 44 (4.6%) after balloon aortoplasty or stent implantation. Most of the aneurysms after primary prosthetic patch repair in our series developed after procedures involving CoA ridge resection and prosthetic patch placement performed before 1988. Neither age nor transverse arch-isthmus hypoplasia were predictors of late aneurysm formation in our series.

In summary, we have demonstrated that surgical repair of recurrent obstruction and aneurysm formation at the site of primary CoA repair produces good and lasting results in the majority of patients and remains the “gold standard” of reintervention. Balloon aortoplasty with or without stenting, with or without covered stents, has become the initial procedure of choice at most institutions including our own, even though one third of patients have complications or persistent obstruction and may eventually require surgery. Transverse aortic arch obstruction, although uncommon, should almost always be approached surgically through sternotomy.

Surgery for re-CoA after an attempted balloon aortoplasty with or without stent is theoretically more treach-

erous for the patients than initial redo surgery. The bridging collaterals that formed during the recurrence may regress rapidly after balloon aortoplasty and may result in a lower distal aortic pressure during surgery and clamping of the aorta. Left-side heart bypass or femoral artery/femoral vein bypass is more likely to be required under these circumstances because the distal aortic pressures falls below the desired level of 40 to 50 mm Hg or the evoked potentials may diminish. Both patients who had aneurysms after stent placement required left-side heart bypass. If a stent was utilized and failed to adequately treat the recurrence, then that segment of the aorta will likely require resection and graft interposition as the stent can rarely be removed without destroying the integrity of the aortic wall. Stent failure may increase the necessity to do an extra-anatomic bypass of the recurrent CoA. The incidence of recurrence is decreasing in most centers. Patients who have recurrence will require long-term follow-up, and the methodology to address recurrence will continue to evolve.

It is conservative to say that most patients with severe long-segment re-coarctation are best treated with redo surgery. Patients with less severe, shorter segment re-CoAs should have an initial trial of balloon aortoplasty. Stent placement should be reserved for teenagers and adults in whom continued growth of the aorta is not desired or expected. Prevention of recurrence will continue to be the goal of surgery for primary coarctation.

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DISCUSSION

DR JOSEPH M. FORBESS (Dallas, TX): I have a technical question. If you're going back in the left chest for a recurrent coarctation, do you, in general, not dissect out the medial side of these vascular structures? Do you just get enough out to lay a side-biting clamp across the coarcted area? I'm noticing you have a very low incidence of recurrent nerve injuries, and I was just wondering if that's because you're staying away from that area entirely.

DR BROWN: At the time of initial coarctation surgery we close the pleura over the repair. This facilitates a redo greatly. We routinely circumferentially dissect out the aorta to gain full proximal and distal control. I've never felt very secure with a side-biter in redo coarctation surgery.

DR DOMINIQUE R. METRAS (Marseille, France): Looking at your conclusions, does this mean that you recommend surgery for all recoarctations, or if not, how do you choose to have dilatation or surgery? How do you make the decision?

DR BROWN: Your last statement was correct. We rarely discuss the therapeutic option until after the cardiologist have already attempted balloon angioplasty. Basically we only get referred after their unsuccessful attempts or complications. The cardiologists see the patients first. Although we discuss all of the patients requiring surgery with our cardiologists ahead of time, our cardiologists rarely discuss their modes of therapy with us before they intervene. I doubt that our situation is much different than your experience in your institution.

DR CARL L. BACKER (Chicago, IL): John, I believe you previously published your surgical results with recoarctation more than 10 years ago. You concluded that reoperation was the gold standard for recoarctation then, and I think you've confirmed that it is still the gold standard. I have two questions.

In some patients you used an interposition graft and in some patients a Dacron patch. I have to admit that in patients that

have a recoarctation that are adult size I have switched from using the patch technique to an interposition graft for fear of aneurysm formation. I noticed you did not have any late aneurysms, but other people have reported them. Why did some of those patients get an interposition graft? Is that part of a recent change in strategy, or are you still recommending a patch as the primary procedure?

DR BROWN: Carl, most of our patients who had interposition grafts had aneurysms after their initial repair, and at redo I wanted to get rid of all of the abnormal aortic tissue. So, some of our patients who came back for recoarctation did have aneurysms. And the majority of the aneurysms occurred after the first or initial surgery using a prosthetic patch.

DR BACKER: The other thing I wanted you to just mention was—because I've taken out some of these stents that the cardiologists have put in, and I have to say it's not a very fun day; so far the ones that I've done, I've ended up doing with partial bypass because of the risk of paraplegia now that they've got good flow—so maybe you could tell us, I think you had 3 patients that you took stents out of, maybe you could tell us a little bit about those 3 patients.

DR BROWN: One of our stent patients had migration and obviously we had to go after the stent and take it out. The other stent removals occurred late after initial intervention. One of our stent patients had a mycotic aneurysm around the stent. This child had his coarctation fixed at age 5 and had a recurrence, had a stent put in, and about a month later he became febrile and presented very ill, and the chest x-ray film showed a huge mass in the region of his distal aortic arch. We took him to the operating room, and there was a huge amount of pus surrounding that portion of his aorta. That entire portion of his aorta had to be resected and replaced with an aortic homograft. That patient was placed on left heart bypass for us to be able to get proximal and distal control. And the other patient was a patient

who had an aneurysm after the stent was put in and probably before the days of stent grafts. After the aneurysm developed, the cardiologists felt this patient needed to go to the operating room and have the aneurysm resected.

But you raise an extremely important point, that when you go back in on a patient who has had angioplasty or stenting, or both, the collaterals have regressed and the risks for paraplegia are higher. We use a somatosensory evoked potentials on all of our coarctations and have for 20 years, and so we use that as a guide as to whether we need bypass or not.

DR FORBESS: I would add that, because it's so treacherous heading right back in the same pathway—just an advertisement for what we presented at the CHSS—we've gone to the right chest and just put a graft from the ascending aorta to the descending aorta and left the stent in place rather than try and extricate it.

DR BROWN: I recently had an opportunity to do an extra-anatomic bypass of a recurrent coarctation a couple of weeks ago, but that patient is not in this database.