

## Acute Results of Balloon Angioplasty of Native Coarctation Versus Recurrent Aortic Obstruction Are Equivalent

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**Objectives.** This study sought to compare the immediate results and risk factors for suboptimal outcomes of percutaneous balloon angioplasty for native versus recurrent aortic obstruction.

**Background.** Some cardiology centers have been reluctant to adopt balloon angioplasty for treatment of native aortic coarctation, while advocating balloon angioplasty over an operation for treatment of postsurgical or recurrent aortic obstruction.

**Methods.** Acute results were analyzed from 970 procedures (422 native and 548 recurrent lesions) performed between 1982 and 1995 in 907 patients from 25 centers. An acute suboptimal outcome was defined as one or more of the following: residual systolic pressure gradient  $\geq 20$  mm Hg, residual proximal to distal systolic pressure ratio  $\geq 1.33$  or a major complication (death, aortic transmural tear, stroke).

**Results.** Balloon angioplasty significantly ( $p = 0.0001$ ) increased lesion diameter for both native (mean [ $\pm$ SD]  $128 \pm 94\%$ ) and recurrent aortic obstruction ( $97 \pm 87\%$ ), with a significantly greater increase in the native group ( $p = 0.0001$ ). A reduction in systolic pressure gradients was significant in both groups ( $p =$

$0.0001$ ), but slightly higher ( $p = 0.01$ ) for native ( $-74 \pm 24\%$ ) versus recurrent obstruction ( $-70 \pm 31\%$ ). Death associated with angioplasty was reported in 0.7% of patients with native and in 0.7% of patients with recurrent lesions ( $p = 1.00$ ). An acute suboptimal outcome was noted with angioplasty in 19% of native and in 25% of recurrent lesions ( $p = 0.04$ ). Significant independent risk factors included higher preangioplasty systolic gradient (odds ratio [OR] 1.39/10-mm Hg increment; 95% confidence interval [CI] 1.28 to 1.50,  $p = 0.0001$ ), earlier study date (OR 0.92/1-year increment, 95% CI 0.87 to 0.96,  $p = 0.0006$ ), older age (OR 1.13/5-year increment, 95% CI 1.02 to 1.26,  $p = 0.02$ ) and recurrent obstruction (OR 1.39 vs. native lesions, 95% CI 1.00 to 1.94,  $p = 0.05$ ).

**Conclusions.** Acute results and complications of balloon angioplasty of native coarctation appear to be equivalent or slightly superior to those of recurrent aortic obstructions.

(*J Am Coll Cardiol* 1996;28:1810-7)

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Some cardiology centers have been reluctant to adopt percutaneous balloon angioplasty for native aortic coarctation, while advocating balloon angioplasty over surgical repair for postsurgical or recurrent aortic obstruction. This was evident in the early reports from the Valvuloplasty and Angioplasty of Con-

genital Anomalies (VACA) Registry (1,2). Concerns about an increased risk of acute aortic transmural tear or rupture, vascular complications in neonates and infants and an increased incidence of late aortic aneurysm formation contributed to this reluctance to adopt balloon angioplasty for native aortic coarctation. This viewpoint related to acute results has been challenged (3). Direct comparisons of acute results of balloon angioplasty for native coarctation versus recurrent aortic obstruction have not been made.

We sought to compare the characteristics and acute results of percutaneous balloon angioplasty for native versus recurrent aortic obstruction and to determine independent risk factors for an acute suboptimal result.

### Methods

**Study group.** Immediate results from a total of 1,157 consecutively attempted percutaneous balloon aortic angio-

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Manuscript received March 21, 1996; revised manuscript received June 20, 1996, accepted August 13, 1996.

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**Abbreviations and Acronyms**

CI = confidence interval  
OR = odds ratio

plasty procedures performed between April 1982 and September 1995 were submitted from 38 institutions. This includes 341 procedures performed before December 1986, for which the method of data collection and acute results have been previously reported (2,4). Data from 11 institutions reporting 87 procedures were excluded, as these institutions had not submitted data to the Registry since 1990 and were not considered current. An additional two noncurrent institutions reporting 100 procedures were also excluded, as these institutions had withdrawn from participation in the Registry. The final study entity therefore consisted of 970 procedures performed in 907 patients from 25 institutions. Procedures were divided into two groups. The first group comprised those procedures in patients with native thoracic aortic coarctation who had not had previous procedures, and excludes patients with supravalvar aortic stenosis or abdominal aortic coarctations. The second group includes patients with residual, recurrent or surgically acquired thoracic aortic obstructions either after balloon angioplasty of native obstructions or after surgical coarctation repair, a Norwood procedure or repair of interrupted aortic arch, and are hereafter referred to as *recurrent aortic obstructions*.

**Data collection.** Data collected for each procedure included the date of procedure and operator, patient selection characteristics such as age, aortic dimensions, the presence of associated cardiac lesions and previous procedures and hemodynamic data from cardiac catheterization. Aortic dimensions were obtained from standard predilation angiography with correction for magnification. Technical factors included the diameter of the balloon(s) and the use of a simultaneous double balloon technique. This was related to the diameter of the aorta proximal to the area of stenosis. When a double balloon technique was used, the effective dilating diameter for two simultaneous balloons was calculated using the formula published by Yeager (5). Outcomes assessed included the immediate postdilation angiographic aortic measurements and hemodynamic data, as well as complications and mortality.

**Data analysis.** The distributions of values for predictor and outcome variables were determined, and frequencies are reported for categoric and ordinal variables and means ( $\pm$ SD) or medians (ranges) for continuous variables, depending on their distributions. Numbers of patients are given when data are missing. All analyses were performed using SAS statistical software (6). Comparisons of angioplasty for native versus recurrent aortic obstructions were made using the Fisher exact test, chi-square test, *t* test and Kruskal-Wallis analysis of variance. Changes in dimensions and hemodynamic data, reported as the percent change from baseline, were compared using paired *t* tests.

To determine independent factors predictive of acute results, a suboptimal outcome was arbitrarily defined as the presence of one or more of the following: residual peak to peak systolic pressure gradient  $\geq 20$  mm Hg, residual ratio of proximal to distal peak systolic pressure  $\geq 1.33$  or a major complication, including death, aortic tear or stroke. Significant predictors from bivariate analyses were further tested using multiple logistic regression analysis with a forward and backward stepwise variable selection method, with  $p = 0.05$  as criteria for variable selection or removal. Results are reported as odds ratios (with 95% confidence interval) for a given increment for continuously measured variables, and relative to a reference category for categoric variables. Odds ratios of 1 imply no effect on risk,  $>1$  an increased risk and  $<1$  a decreased risk. Continuously measured variables were further analyzed by categorizing them and reentering them into the final logistic regression model to determine the nature of the relation to the outcome.

## Results

**Patient characteristics.** Of the 970 procedures included, 422 were for angioplasty of native aortic coarctation and 548 for recurrent aortic obstruction, with the total number of procedures reported per institution ranging from 3 to 222 (median 15, mean 39). Of the 25 institutions, five reported no angioplasty procedures for native coarctation, and another five reported native coarctation angioplasty for  $<10\%$  of reported procedures. Institutions with higher volumes reported greater proportions of procedures for native coarctation.

For those with recurrent coarctation, previous procedures included resection with end to end anastomosis in 96 (17%), left subclavian artery flap angioplasty in 79 (14%), synthetic patch angioplasty in 59 (11%), Norwood procedure in 42 (8%), extensive aortic arch reconstruction or conduit in 27 (5%), multiple operations in 10 (2%), previous balloon angioplasty only in 36 (7%), both previous surgery and balloon angioplasty in 12 (2%) and an unknown type of native coarctation repair in 187 (34%).

**Comparison of native versus recurrent aortic obstruction balloon angioplasty.** *Preangioplasty characteristics and early outcomes.* Both groups were similar regarding preangioplasty characteristics (Table 1), with the exception of an earlier date of procedure, more complex associated anomalies and a higher ratio of stenotic lesion to proximal aortic diameter in the recurrent aortic obstruction group. When comparing outcomes, significant increases in stenotic lesion dimension and reductions in hemodynamic obstruction were noted in both groups, but were slightly greater for native coarctation (Table 2). Complications were similar for both groups, with the exception of more reported intimal tears or flaps in the native coarctation group, and a greater proportion of those in the recurrent obstruction group having received blood products.

*Mortality.* Seven deaths were reported—three patients with native coarctation and four with recurrent obstructions. Of the

**Table 1.** Comparison of Native Versus Recurrent Aortic Obstruction Preangioplasty Characteristics

Characteristic	Native (n = 422)	Recurrent (n = 548)	p Value
Mean study interval (yr)*	7.9 ± 3.1	7.4 ± 3.1	0.02
Patient age	(n = 419)	(n = 540)	
Median	4.2 yr	2.7 yr	0.98
Range	2 days-63 yr	15 days-54 yr	
Associated cardiac anomalies			
Aortic valve stenosis	30 (7%)	26 (5%)	0.12
Subaortic stenosis	13 (3%)	19 (4%)	0.74
Bicuspid aortic valve	44 (10%)	44 (8%)	0.20
Mitral valve stenosis	12 (3%)	12 (2%)	0.52
Ventricular septal defect	39 (9%)	55 (10%)	0.68
Complex anomalies	13 (3%)	84 (15%)	0.0001
Use of simultaneous double-balloon technique	16 (4%)	26 (5%)	0.47
Mean ratio of balloon to proximal aortic diameter	1.07 ± 0.21 (n = 266)	1.10 ± 0.25 (n = 311)	0.07
Mean aortic diameter (mm)			
Proximal	10.5 ± 4.6 (n = 266)	10.2 ± 4.2 (n = 383)	0.38
Stenotic lesion	4.4 ± 2.8 (n = 298)	5.0 ± 2.9 (n = 419)	0.01
Distal	12.8 ± 5.5 (n = 225)	12.0 ± 5.1 (n = 360)	0.06
Mean ratio of stenotic lesion to proximal aortic diameter	0.41 ± 0.15 (n = 232)	0.48 ± 0.20 (n = 360)	0.0001
Mean systolic gradient (mm Hg)	42 ± 18 (n = 413)	41 ± 22 (n = 542)	0.44
Mean ratio of proximal to distal systolic pressure	1.52 ± 0.26 (n = 411)	1.51 ± 0.37 (n = 538)	0.80

\*Interval from first reported procedure to VACA Registry. Data presented are mean value ± SD or number (%) of patients, unless otherwise indicated.

three patients with native coarctation, one had Shone's syndrome (age 13 months), one had a complex single ventricle (9 days) and one had isolated coarctation (age 6 months). All were critically ill before the procedure and died in the catheterization laboratory. Autopsy in two of them showed intimal tears but no aortic rupture, and postdilation angiography in the third showed a good result with no aortic disruption. These deaths were presumed to be related to the premorbid condition of the patient and not as a direct result of the procedure.

Of the four patients with recurrent obstruction, one had isolated recoarctation after patch aortoplasty (age 11 months), one had complex ventricular inversion and recoarctation after left subclavian artery flap aortoplasty (age 2.6 years) and two had recurrent obstruction after stage I Norwood aortic arch reconstruction (age 2.6 and 4.3 months). One of these latter patients, who was in critical condition during the procedure, had a cardiac arrest shortly after dilation; no autopsy was performed. The other patient who had a Norwood procedure underwent successful dilation but died 1 h later of retroperitoneal bleeding due to a tear in the iliac artery; autopsy showed that the aortic dilation site was intact. The patient with complex ventricular inversion was stable after the procedure

but died unexpectedly 14 h later; autopsy showed the aortic dilation site was intact with good relief of obstruction. The final patient with isolated coarctation had an uneventful dilation but developed neurologic signs after the procedure. Investigations revealed hemorrhagic cerebral infarcts, and the patient developed acute cerebral edema with herniation and brain death. Autopsy revealed an incomplete circle of Willis, and the cerebral event was thought to be due to occlusion of the left carotid artery by the dilating catheter during the dilation.

**Risk factors for a suboptimal outcome.** A suboptimal outcome, as previously defined, was noted for 80 procedures (19%) for native coarctation and 135 procedures (25%) for recurrent obstruction ( $p = 0.04$ ). If we arbitrarily define a difference of at least 5% as clinically significant, we have a power of 0.60 at alpha 0.05 to detect this difference. Our observed difference was greater than this, although marginally so, and we therefore are confident in concluding that the reported superiority of dilation of recurrent obstructions over native coarctation is not valid. In bivariate analysis, significantly more suboptimal outcomes occurred earlier in the experience ( $p = 0.0001$ ). Patients with a suboptimal outcome were significantly older (median age 4.1 vs. 3.5 years;  $p = 0.04$ ). There were no significant differences regarding associated cardiac anomalies. There was no effect of ratio of balloon to proximal aortic diameter on suboptimal outcome, with a mean ratio of  $1.09 \pm 0.29$  ( $n = 129$ ) for patients with a suboptimal outcome versus  $1.09 \pm 0.21$  ( $n = 448$ ) for those without a suboptimal outcome ( $p = 0.83$ ). This ratio also had no significant effect on any outcome variable for either native or recurrent obstruction. Before angioplasty, patients with a suboptimal outcome had similar ratios of proximal to stenotic lesion diameter, but significantly higher systolic gradients ( $53 \pm 22$  [ $n = 211$ ] vs.  $39 \pm 19$  mm Hg [ $n = 744$ ],  $p = 0.0001$ ) and higher ratios of proximal to distal systolic pressure ( $1.67 \pm 0.42$  [ $n = 209$ ] vs.  $1.47 \pm 0.28$  [ $n = 740$ ],  $p = 0.0001$ ). Patients with suboptimal outcomes had lesser percent increases in the stenotic lesion diameter ( $91 \pm 86\%$  [ $n = 124$ ] vs.  $115 \pm 92\%$  [ $n = 478$ ],  $p = 0.008$ ) and lesser percent increases in the ratio of stenotic lesion to proximal aortic diameter ( $85 \pm 85\%$  [ $n = 62$ ] vs.  $111 \pm 92\%$  [ $n = 252$ ],  $p = 0.04$ ).

**Independent risk factors.** Significant independent risk factors for early suboptimal outcome included a higher preangioplasty systolic gradient, earlier procedure date, older patient age and recurrent obstruction (Table 3). When procedures from institutions that had not reported any dilation procedures for native aortic obstructions were excluded ( $n = 44$ ), age and recurrent obstruction no longer entered significantly into the multiple logistic models, with no change in the odds ratios for preangioplasty gradient or date of procedure.

**Preangioplasty systolic gradient and patient age.** The independent effect of preangioplasty systolic gradient was further explored by categorizing this variable and reentering it into the final regression model. The independent effect of systolic gradient appears to be linear (Fig. 1). Patient age was likewise analyzed

**Table 2.** Comparison of Acute Results of Balloon Angioplasty of Native Versus Recurrent Aortic Obstruction

Characteristic	Native (n = 422)	Recurrent (n = 548)	p Value
Mean change in aortic diameter			
Proximal	+2 ± 11% (n = 102, p = 0.07)	+2 ± 15% (n = 223, p = 0.13)	0.75
Stenotic lesion	+128 ± 94% (n = 259, p = 0.0001)	+97 ± 87% (n = 343, p = 0.0001)	0.0001
Distal	+3 ± 15% (n = 91, p = 0.04)	+1 ± 7% (n = 123, p = 0.02)	0.23
Mean ratio of stenotic lesion to proximal aortic diameter after angioplasty	0.84 ± 0.18 (n = 98)	0.83 ± 0.22 (n = 205)	0.78
Mean change in ratio of stenotic lesion to proximal aortic diameter	+125 ± 90% (n = 96, p = 0.0001)	+98 ± 90% (n = 218, p = 0.0001)	0.01
Median systolic gradient after angioplasty (mm Hg)	9 (0-65) (n = 412)	9 (0-82) (n = 509)	0.44
Mean ratio of proximal to distal systolic pressure after angioplasty	1.11 ± 0.10 (n = 404)	1.13 ± 0.15 (n = 477)	0.05
Mean change in hemodynamic variables			
Systolic gradient	-74 ± 24% (n = 405, p = 0.0001)	-70 ± 31% (n = 530, p = 0.0001)	0.01
Ratio of proximal to distal systolic pressure	-26 ± 11% (n = 399, p = 0.0001)	-23 ± 14% (n = 498, p = 0.0001)	0.005
Complications			
Any complication	63 (15%)	72 (13%)	0.41
Death	3 (0.7%)	4 (0.7%)	1.00
Transmural aortic tear	0	4 (0.7%)	0.14
Neurologic event	3 (0.7%)	3 (0.6%)	1.00
Reported intimal tear/flap	22 (5.2%)	9 (1.6%)	0.002
Vascular			
Pulse loss	19 (4.5%)	10 (3.7%)	0.50
Thrombolysis required	1 (0.2%)	3 (0.6%)	0.64
Operation required	2 (0.5%)	7 (1.3%)	0.31
Blood products given	13 (4.1%)	52 (15%)	0.0001

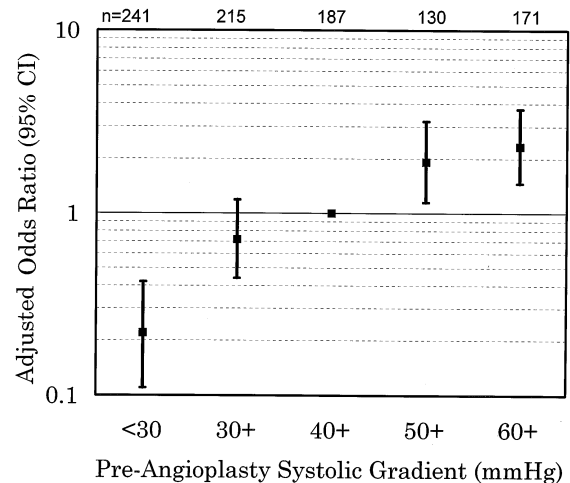
Data presented are mean value ± SD, median (range) or number (%) of patients.

and showed an overall trend of increasing risk with increasing age, with a slightly increased risk in neonates (Fig. 2).

*Type of aortic obstruction.* The independent effect of specific aortic obstruction subtypes was also explored (Fig. 3). With native coarctation set as the reference group, patients who had coarctation repair with resection with end to end anastomosis (p = 0.04) or synthetic patch angioplasty (p = 0.03) had a significantly higher adjusted risk of acute suboptimal outcome than patients with native coarctation. Increased

but not significant risk was noted for patients who had aortic arch reconstruction, multiple operations or a combination of surgical repair and balloon angioplasty.

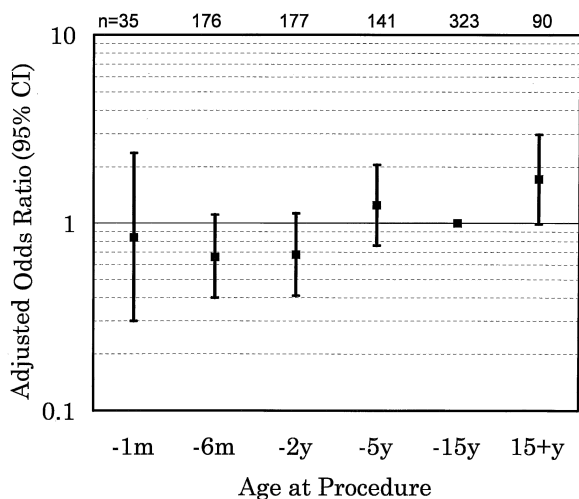
**Figure 1.** Independent effect of preangioplasty systolic pressure gradient on risk of a suboptimal outcome. Odds ratios with 95% confidence intervals (CI) adjusted for procedure date, patient age and recurrent obstruction from multiple logistic regression are plotted against preangioplasty systolic gradient.



**Table 3.** Independent Risk Factors for a Suboptimal Outcome\*

Characteristic	OR (95% CI)	p Value
Preangioplasty systolic gradient (per 10-mm Hg increment)	1.39 (1.28-1.50)	0.0001
Study interval (per 1-year increment)	0.92 (0.87-0.96)	0.0006
Patient age (per 5-year increment)	1.13 (1.02-1.26)	0.02
Recurrent obstruction (vs. native coarctation)	1.39 (1.00-1.94)	0.05

\*From multiple logistic regression analysis (n = 944); suboptimal outcome was defined as one or more of the following: residual systolic pressure gradient ≥20 mm Hg, residual proximal to distal systolic pressure ratio ≥1.33 or major complication defined as death, transmural aortic tear or stroke. CI = confidence interval; OR = odds ratio.

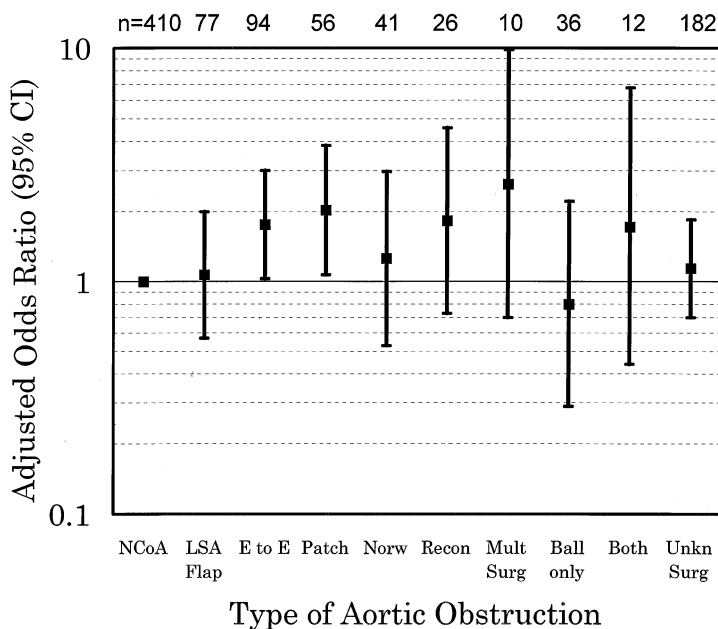


**Figure 2.** Independent effect of patient age on risk of a suboptimal outcome. Odds ratios with 95% confidence intervals adjusted for preangioplasty systolic pressure gradient, procedure date and reocclusion from multiple logistic regression are plotted against patient age. m = month or months; y = years.

*Institutional experience.* The significant effect of date of procedure was also explored to determine the effect of evolving experience on acute results. Variables reflective of experience were created and included number of procedures (number of procedures reported by a given institution), time of adoption of procedure (time from first ever reported procedure to the Registry to the first procedure reported by each institution), length of experience (time from an institution's first to the most recent procedure reported from a given institution), intensity of experience (total number of procedures divided by the length of experience for a given institution), time of procedure (time from first ever procedure reported from an

institution to each subsequent procedure from a given institution, and time from the first ever procedure reported to the Registry to each procedure reported). When these variables were tested with stepwise selection in a multiple logistic regression model including pre-angioplasty gradient, age and recurrent versus native obstruction, only an institution's total number of procedures and the time of each case in the whole Registry's experience were significant. Exploration by categorization of the variable institution's total number of procedures showed that the increased risk was greatest for procedures performed at institutions that had reported  $\leq 50$  procedures. Odds of a suboptimal outcome relative to procedures reported from institutions reporting  $>100$  procedures (odds ratio [OR] set at 1.00) were as follows for each institutional reporting category: 10 or fewer procedures, OR 1.96; 11 to 20 procedures, OR 1.94; 21 to 50 procedures, OR 2.74; 51 to 100 procedures, OR 1.09. This was unrelated to the time over which the number of procedures had been performed. Likewise, the variable time of each case in the Registry's experience was categorized and reentered into the multiple logistic model. Relative to the most current 5 years, increased odds of an acute suboptimal outcome was greatest for the first 2 years (OR 6.26) and decreased over the intervening 6 years (OR 1.69) of the Registry's reported experience. These institutional experience effects are significant after controlling for differences relating to pre-angioplasty gradient, age and recurrent obstruction.

*Suboptimal relief of obstruction.* A similar analysis was performed to determine independent risk factors for suboptimal relief of obstruction only, defined as an immediate residual systolic gradient  $\geq 20$  mm Hg or a proximal to distal pressure ratio  $\geq 1.33$ , regardless of complications. This outcome was noted for 18% of procedures for native coarctation versus 26% of procedures for recurrent aortic obstruction ( $p = 0.02$ ). In logistic regression analysis the same risk factors as for an acute suboptimal outcome were significant for suboptimal relief of



**Figure 3.** Independent effect of specific previous procedures on risk of a suboptimal outcome. Odds ratios with 95% confidence intervals (CI) adjusted for preangioplasty systolic pressure gradient, procedure date and patient age from multiple logistic regression are plotted against specific previous procedures. Ball = balloon angioplasty; both = both previous surgical repair and balloon angioplasty; E to E = resection with end to end anastomosis; LSA flap = left subclavian artery flap angioplasty; NCoA = native coarctation; mult surg = multiple previous surgical repairs; Norw = Norwood procedure; patch = synthetic patch angioplasty; recon = aortic arch reconstruction; unkn surg = unknown type of surgical repair.

obstruction, with similar odds ratios as follows: preangioplasty systolic gradient, 1.42/10-mm Hg increment ( $p = 0.0001$ ); study time interval, 0.93/1-year increment ( $p = 0.004$ ); patient age, 1.15/5-year increment ( $p = 0.01$ ); and recurrent obstruction, 1.43 versus native coarctation ( $p = 0.04$ ). Balloon to proximal aortic diameter ratios were not significantly related to relief of obstruction.

## Discussion

Our analysis of 970 percutaneous balloon aortic angioplasty procedures showed early relief of obstruction without major complications for 81% of procedures for native coarctation and 75% of procedures for recurrent aortic obstruction. Major complications (death, transmural aortic tear, stroke) were noted for only 1.6% of procedures.

**Study limitations.** This study represents the largest series of patients undergoing percutaneous balloon angioplasty of aortic obstruction. The results must, however, be viewed in light of the limitations of this study. The recurrent obstruction group is very heterogeneous regarding the type of previous procedures that had been performed. However, the large patient numbers in this study permitted subgroup analysis in multiple logistic regression analysis, with adjustments made for other significant predictors of outcome. No attempt was made to standardize patient selection or procedural techniques between or within institutions. Readers interested in learning more about recommended techniques and controversies surrounding technical details of these procedures are referred to textbooks by Lock et al. (7) and Rao (8). Information related to other potentially important predictors and outcomes was not collected. The site of measurement of proximal and distal aortic diameters was not standardized. Measurements collected did not allow consideration of whether associated proximal aortic arch hypoplasia was present, and these patients were not excluded. Similar but significant amounts of measurement data are missing, and the results of analysis of changes in aortic dimensions and the effect of the ratio of balloon to proximal aortic diameter must be viewed with particular caution. Systematic reporting bias cannot be ruled out.

**Risk factors for an early suboptimal outcome.** Risk factors were carefully evaluated and included a higher preangioplasty systolic pressure gradient, earlier procedure date, older patient age and presence of recurrent obstruction. Beekman et al. (4) also observed a relation between higher pre-angioplasty gradient and suboptimal outcomes. Rao and Kosciak (9) identified a smaller isthmus to proximal aortic dimension before angioplasty as a significant risk factor for recurrence after dilation of native coarctation.

Unlike with balloon dilation of valvar obstructions, the degree of immediate gradient reduction was not significantly related to balloon sizing. This may reflect the heterogeneity of anatomic mechanisms of aortic obstruction, variations or errors in measurements and the effect of associated transverse aortic arch hypoplasia. Tyagi et al. (10) showed poor results with dilation of long segment tubular versus discrete native

coarctations. Anjos et al. (11) showed an effect of increased ratio of balloon to distal aortic diameter on improved results at follow-up after dilation of recurrent coarctation. A preliminary study of the adjunctive use of balloon-expandable stents has shown further improvement in early results (12).

Institutional factors were associated with outcome. More recent improved results may be related to increasing operator skill and experience and to improvements in balloon and catheter technology. The institutions reporting the largest procedural volumes might also be expected to have operators with the greatest experience. In a similar analysis of percutaneous balloon aortic valvotomy, an individual operator's successive experience was most predictive of improving results (13).

Increasing patient age predicted poor results, and was suggested by Hellenbrand et al. (1) in an earlier report from the VACA Registry. Long-standing aortic obstruction may be associated with increased fibrotic change in the aorta and might suggest a plan of earlier rather than later intervention by balloon angioplasty techniques. However, this finding may not reflect follow-up results, and some series have shown an increased risk of recurrence in younger patients (9,14,15).

Risk of an early suboptimal outcome was greater with recurrent aortic obstructions and was related to the specific type of previous procedure(s). This may reflect differing degrees of distensibility secondary to increased scar formation associated with certain types of surgical repairs.

Although early results may be slightly better for native coarctation, data regarding long-term outcome may be of greater interest. Encouraging medium-term follow-up results of balloon angioplasty of native coarctations have been reported and suggest that beyond infancy obstruction relief is maintained (14,15). Native coarctation dilations in neonates and infants remain controversial, and despite good early results a significant recurrence risk is reported (9,14-17). We show that repeat balloon angioplasty is successful for recurrent obstruction after initial balloon angioplasty.

**Balloon angioplasty of native versus recurrent aortic obstruction.** Over the period of this multicenter experience a shift in practice occurred, with more dilations of native coarctation being reported later, implying an initial reluctance to adopt balloon angioplasty of native coarctations (3). Several factors may be implicated. There was a bias that dilation of recurrent obstructions was safer because of the supporting surgical scar tissue, with a reduced risk of acute aortic rupture. We have shown that transmural aortic tears have not been seen with dilation of native coarctations, and are rare with dilation of recurrent obstructions. Aneurysm formation at dilation sites remains a long-term concern. Preexisting cystic medial necrosis commonly noted on histologic examination of aortas with untreated native coarctation may predispose to aneurysm formation (18). In early reports, Brandt et al. (19) and Cooper et al. (20) noted a significant incidence of aneurysm formation during short-term follow-up. More recent single-institution series have reported a much lower incidence of aneurysm formation both in short-term and long-term follow-up

(14,15,21-24). The importance of avoiding overdilation of the coarctation segment by careful balloon size selection is now better understood, and guide wire and catheter manipulation across a freshly dilated coarctation segment is known to increase the risk of aortic tear or perforation (25). The recognition that late aneurysm formation can occur after surgical repair, regardless of the type of repair, may also have contributed to the increased interest in balloon angioplasty treatment for native coarctation (26,27).

Other complications, including the risk of death, were similar in both groups. Causes of death were often related to the condition of the patient before the procedure and not directly to the procedure. Complications related to femoral artery injury were also similar in both groups, but under-reporting may have occurred. The incidence, although comparable to earlier reports from the VACA Registry (1,3), may be higher at follow-up and related to the age at angioplasty (15,28).

**Conclusions.** Balloon angioplasty of native coarctation and recurrent aortic obstruction in children has become a widely applied treatment, as demonstrated in this large multicenter experience. The risk of acute procedural complications is low and obstruction is relieved in the majority of patients. Acute results appear to be equivalent with both native and recurrent obstructions. Comparisons with surgical results are fraught with bias (29). Coarctation of the aorta is a heterogeneous disorder occurring with varying degrees of arch hypoplasia and associated intracardiac defects. By comparing unselected series of surgical and balloon angioplasty series, the two groups are rarely equal and may differ in subtle ways that could have a significant impact on outcomes. Although studies of medium-term follow-up of angioplasty procedures are encouraging, the long-term fate of these dilated aortas must await long-term follow-up studies of large series of patients.

## Appendix

### *Participating VACA Registry Investigators*

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