Aortic Valve Reinterventions After Balloon Aortic Valvuloplasty for Congenital Aortic Stenosis

Intermediate and Late Follow-Up

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Objectives

The aim of this study was to evaluate the long-term results of transcatheter balloon aortic valvuloplasty, the preferred treatment for congenital aortic stenosis (AS).

Background

Aortic valve function and reintervention late after this procedure are not well characterized.

Methods

From 1985 to 2008, 563 patients underwent balloon dilation for congenital AS. After excluding those converted to univentricular circulation and/or died ≤30 days after the procedure, 509 patients constituted the study cohort.

Results

The median follow-up period was 9.3 years (range 0.1 to 23.6 years); cumulative follow-up was 5,003 patient-years. The median age was 2.4 years (range 1 day to 40.5 years), and most patients (73%) had isolated native AS. Peak AS gradients decreased significantly after dilation (median decrease, 35 mm Hg), and acute post-dilation aortic regurgitation was moderate or greater in 70 patients (14%). Older patients more often had post-dilation aortic regurgitation (p < 0.001). During follow-up, 225 patients (44%) underwent aortic valve reintervention: repeat balloon dilation in 115 (23%), aortic valve repair in 65 (13%), and aortic valve replacement in 116 (23%). Survival free from any aortic valve reintervention was 89.1% at 1 year, 72.2% at 5 years, 54.3% at 10 years, and 27.3% at 20 years. Freedom from aortic valve replacement was 90.2% at 5 years, 79.3% at 10 years, and 53.4% at 20 years. In multivariate analyses, lower post-dilation AS gradient and lower grade of post-dilation aortic regurgitation were associated with longer freedom from aortic valve replacement, but age, era, and pre-dilation AS severity were not.

Conclusions

Although transcatheter aortic valvuloplasty is effective for relief of congenital AS, there are steady long-term hazards for surgical aortic valve reintervention and replacement that are independent of age at initial intervention or AS severity. (J Am Coll Cardiol 2010;56:1740–9) © 2010 by the American College of Cardiology Foundation

First reported 26 years ago (1), balloon aortic valvuloplasty has become the preferred treatment for newborns, children, and young adults with congenital aortic stenosis (AS) at most centers (2–12). Factors associated with technical success and short-term and midterm outcomes of balloon valvuloplasty for congenital AS have been characterized in a number of studies (2–4,6,10,11,13,14). However, there is limited information on the long-term function of the aortic valve or the frequency of or risk factors for aortic valve replacement (AVR) or other forms of aortic valve reintervention after balloon dilation (9,12). The objective of this retrospective cohort study was to characterize freedom from aortic valve reinterventions and patient-related and procedural risk factors for reintervention in a large cohort of patients treated over a 24-year period.

Methods

Patients. Patients with diagnoses of congenital valvular AS who underwent transcatheter balloon valvuloplasty at Children’s Hospital Boston from December 1984 through January 2009 were ascertained from the computer database of the Department of Cardiology. Patients who died or were converted to functionally univentricular circulation within 30 days of catheterization were excluded. Patients who underwent aortic valve reintervention within 30 days and survived with biventricular circulation were included. Patients with associated congenital cardiovascular anomalies were included, as were those who underwent prior surgical or transcatheter aortic valve intervention before referral to...
our center. Patent ductus arteriosus in newborns, patent foramen ovale, and atrial septal defects not treated surgically were not counted as “associated cardiovascular anomalies.” Indications for catheterization and valve dilation were not standardized and may have varied according to patient age, clinical status, era, referring physician, and catheterizing physician. General guidelines for intervention considered symptomatic status, AS gradient, ventricular function, and the presence and severity of associated anomalies. From 1985, balloon dilation was the first-line therapy for congenital AS at our center, and surgical aortic valvotomy would have been performed almost exclusively in patients with coexisting anomalies requiring open heart surgery or for unsuccessful balloon dilation. Cross-sectional follow-up was obtained by June 2009.

A subset of patients in this cohort were included in previous reports detailing left-heart adequacy in neonates with AS and left-heart growth, function, and reintervention after neonatal balloon aortic valve dilation (11,13). These patients were included in the present study primarily to allow assessment of the relationship between age at intervention and long-term valve-related outcomes.

Aortic valve function. Pre-intervention AS severity was measured as the peak systolic gradient recorded in the catheterization laboratory using simultaneous (preferentially) or pullback pressure recordings. Pre-intervention gradient was captured as a continuous variable and also grouped into categories according to thresholds used in the Second Joint Study on the Natural History of Congenital Heart Defects (≤49, 50 to 79, and ≥80 mm Hg) (15).

Acute post-intervention AS gradient was reported as the peak gradient measured at the end of the procedure by simultaneous or pullback pressure measurement. Post-intervention gradients were grouped into clinically relevant categories according to inflections in the receiver-operating characteristic curve for gradient and aortic valve reintervention (time-independent). Aortic regurgitation (AR) was graded angiographically as none, trace (trivial), mild (1+), and moderate through severe (2+, 3+, and 4+), also referenced as moderate-severe.

Balloon dilation of the aortic valve. The technical details of aortic valve dilation have been described previously (2,3,6). Our general approach is to begin dilation with a balloon diameter <90% of the diameter of the aortic annulus and to progress with higher pressure inflation of the same balloon and/or larger balloons as necessary to achieve an adequate therapeutic approach. Of course, balloon, catheter, and guidewire technology evolved over the course of this experience, so the equipment used varied over time, with balloons and wires conforming with current technology. Other technical variations, such as antegrade dilation and rapid ventricular pacing, were used variably at the discretion of the various operators. In general, the goal is to reduce the peak gradient as low as possible without causing AR. In situations in which a borderline residual gradient is present (30 to 40 mm Hg, depending on circumstances), the decision to proceed with additional dilation is based in part on the change in AR, if any, up to that point. AR was typically evaluated after balloon inflation, after catheter pullback for assessment of residual AS, using aortography in the ascending aorta.

Data analysis. The primary outcome measure was freedom from AVR among patients surviving >30 days after intervention with biventricular circulation. Secondary outcome measures included freedom from repeat balloon aortic valvuloplasty, freedom from surgical aortic valve reintervention, and survival free from these different forms of reintervention. Time-to-event analyses were performed both as survival free from reintervention, with both death and reintervention treated as events, and as freedom from reintervention, with event-free censoring of patients who died. Kaplan-Meier analysis with log-rank testing and Cox proportional hazards regression were performed to assess the relationship between predictor variables and time to event. The start time was set at 30 days after dilation; for the purposes of analysis, any reinterventions that occurred before 30 days after dilation were considered to occur at time 0. Multivariate Cox regression was performed with forward stepwise entry of predictor variables significant at p ≤ 0.05 on univariate analysis, with adjustment for era (procedure date quartile). Predictor variables included procedure date order (analyzed by quartile), age (continuous) and age group at initial catheterization, isolated native AS (no associated anomalies and no prior interventions), prior aortic valve interventions elsewhere, additional cardiac anomalies, severity of AS before intervention, residual AS gradient measured in the catheterization laboratory after balloon dilation, and degree of acute AR measured in the catheterization laboratory. Predictor variables not specially mentioned in the “Results” section were not significantly associated with the outcome of interest. For Kaplan-Meier analysis of freedom from repeat balloon dilation, patients were censored event free at the time of aortic valve surgery if applicable. Competing risks analysis was also performed, with AVR, death, and survival without AVR as the outcomes. The change in peak AS gradient after dilation was assessed by Wilcoxon signed rank test. Between-group comparisons of continuous variables were performed by 1-way analysis of variance, and assessment of differences between categorical variables was performed using chi-square analysis. Unless otherwise specified, data are presented as mean ± SD or as median (range). Hazard ratios (HRs) are presented with 95% confidence intervals (CIs). Because questions relating to survival in this cohort are the focus of a separate ongoing study, only a limited analysis of mortality was performed.
Results

Patients. Between 1984 and 2008, 563 patients with congenital AS underwent balloon aortic valvuloplasty at Children’s Hospital Boston. Fifty-four of these patients were excluded from the present study because they were converted to functionally univentricular circulation during the same hospitalization, either as part of a planned strategy of left-heart rehabilitation or because of circulatory insufficiency after aortic valve dilation (n = 35), and/or died within 30 days of the balloon dilation (n = 19). The remaining 509 patients constituted the study cohort. Demographic and diagnostic details of these 509 patients are summarized in Table 1. Pre-intervention AS gradients are summarized in Table 2.

The median duration of clinical follow-up (as opposed to simply vital status) was 9.3 years (range 0.1 to 23.6 years). Altogether, 5,003 patient-years of clinical follow-up was obtained. Among patients who underwent balloon dilation before 2006, clinical follow-up data were available for at least 2 years or until the time of death in all but 6 patients. Among more recent patients, none were definitely lost to follow-up (defined as no clinical information for at least 4 years), although in 6 patients, the most recent follow-up was 2 months after dilation.

Survival. Forty-four patients died during follow-up. Survival over time was 95\% at 5 years, 93\% at 10 years, and 88\% at 20 years by Kaplan-Meier analysis, with a steep early hazard for death followed by a steady hazard (Fig. 1).

Acute results of balloon dilation. Peak AS gradients decreased significantly after balloon dilation, with a median decrease of 35 mm Hg (p < 0.001). The distribution of pre-intervention and post-intervention gradients and post-intervention AR is summarized in Table 2 and Figure 2. Older patients (the oldest 2 age groups combined) were significantly more likely have moderate or severe AR than younger patients (p < 0.001). Neonates had significantly lower residual gradients (p < 0.001). There was no clear association between residual gradient and the severity of AR.
Aortic valve reintervention. During follow-up, 225 of the 509 patients surviving ≥30 days with biventricular circulation underwent 338 reinterventions on the aortic valve (Table 3). Survival free from any aortic valve reintervention was 89% at 1 year, 72% at 5 years, 54% at 10 years, 38% at 15 years, and 27% at 20 years (Fig. 3).

Repeat balloon dilation. A total of 149 repeat balloon aortic valve dilation procedures were performed in 115 patients, 5 of which were within 30 days of the initial procedure. Kaplan-Meier survival free from repeat balloon valvuloplasty after the index procedure was 90% at 1 year, 82% at 5 years, 71% at 10 years, and 63% at 20 years (Fig. 4). Factors associated with shorter survival free from repeat balloon dilation on multivariate Cox regression included age ≤30 days at intervention (HR: 5.3; 95% CI: 3.6 to 7.9; p < 0.001) and higher residual AS (per 10 mm Hg) early after intervention (HR: 1.21; 95% CI: 1.07 to 1.35; p = 0.002).

Surgical aortic valve reintervention. Surgical interventions on the aortic valve were performed in 159 patients, including aortic valvuloplasty (16) in 65 and AVR in 116 (Table 3). Forty-nine of these patients had undergone second balloon dilations before aortic valve surgery. Survival free from any surgical aortic valve reintervention was 82% at 5 years, 69% at 10 years, 58% at 15 years, and 45% at 20 years. Freedom from aortic valve surgery (deaths censored event free) was essentially identical: 82% at 5 years, 69% at 10 years, 59% at 15 years, and 46% at 20 years. Results of Cox regression analysis for freedom from surgical aortic valve reintervention are sum-

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**Table 3**

<table>
<thead>
<tr>
<th>Intervention/Reintervention</th>
<th>Number of Patients (Procedures)</th>
</tr>
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<tbody>
<tr>
<td>Any reintervention on the aortic valve</td>
<td>225 (338)</td>
</tr>
<tr>
<td>Repeat BAVP</td>
<td>115 (149)</td>
</tr>
<tr>
<td>Multiple repeat BAVP procedures</td>
<td>30</td>
</tr>
<tr>
<td>Surgical aortic valve reintervention</td>
<td>159 (192)</td>
</tr>
<tr>
<td>Surgical aortic valve repair</td>
<td>65 (65)</td>
</tr>
<tr>
<td>Aortic valve replacement</td>
<td>116 (127)</td>
</tr>
<tr>
<td>Pulmonary autograft</td>
<td>53</td>
</tr>
<tr>
<td>Mechanical valve prosthesis</td>
<td>52</td>
</tr>
<tr>
<td>Homograft aortic root replacement</td>
<td>8</td>
</tr>
<tr>
<td>Bioprosthetic valve</td>
<td>3</td>
</tr>
</tbody>
</table>

AS = aortic stenosis; BAVP = balloon aortic valvuloplasty.
Predictors of shorter freedom from surgical reintervention on multivariate analysis included higher acute post-dilation AS gradient, higher grade of acute post-dilation AR, and the presence of multiple left-heart obstructive lesions; on univariate analysis, procedure date order quartile was not associated with freedom from aortic valve surgery, but when forced into the multivariate model, freedom from aortic valve surgery was shorter in the most recent quartile of patients undergoing balloon valvuloplasty.

AVR. AVR was performed in 116 patients, 21 of whom had previously undergone surgical aortic valve repair. The primary indication for AVR was mixed AR and left ventricular outflow tract obstruction (both at least moderate) in 57 patients, left ventricular outflow tract obstruction (AS and/or subvalvular obstruction) in 27 patients, AR in 23 patients, and unknown in 9 patients (followed elsewhere, limited records available). Survival free from AVR was 86 ± 2% at 5 years, 74 ± 3% at 10 years, 62 ± 3% at 15 years, and 47 ± 4% at 20 years. The results of a competing risks analysis of AVR, death, or survival without AVR are depicted in Figure 1. Freedom from AVR (deaths censored event free) was 90 ± 2% at 5 years, 79 ± 3% at 10 years, 67 ± 3% at 15 years, and 53 ± 4% at 20 years. The results of Cox regression analysis for freedom from surgical aortic valve reintervention are summarized in Table 4. Age group 1 to 10 years, isolated native AS, absence of multiple left-heart obstructive lesions, no aortic valve interventions before treatment at our center, lower post-intervention gradient, and lower grade of post-intervention AR were associated with longer freedom from AVR on univariate Cox regression analysis (representative Kaplan-Meier curves are shown in Fig. 5). Factors associated with longer freedom from AVR on multivariate Cox regression included lower acute post-dilation AS gradient and lower grade of acute post-dilation AR (Table 4, Fig. 5). Notably, freedom from AVR did not differ across our experience (procedure order quartile) and by univariate analysis was shorter in patients age ≥16 years and 11 to 15 years at the time of aortic valve dilation than in neonates, infants, and young children (age 1 to 10 years).

Interactions between residual AS and post-dilation AR. In our initial multivariate model, we tested interaction effects with AR grade entered as an ordinal variable (grades 0 to 4) and post-dilation AS gradient entered as a continuous variable, with no interaction effect reaching significance. To further explore the interaction between post-dilation AR and residual AS gradient, we empirically grouped patients into 6 categories on the basis of the combination of post-dilation AR severity (none-trivial, mild, moderate-severe) and acute residual AS gradient as measured in the catheterization laboratory (≤35 mm Hg, >35 mm Hg). The gradient cutoff was selected as the center of the clinically challenging 30 to 40 mm Hg range. This variable was then entered into multivariate analysis of freedom from AVR along with AR severity on an ordinal scale (grades 0 to 4) and residual AS gradient as a continuous variable. According to this model, the combined variable was significantly associated with freedom from AVR, whereas post-dilation AR and residual AS gradient alone were not (Fig. 6). HRs for the various groups are summarized in Table 5. Of note, patients with residual peak AS gradients >35 mm Hg and only mild AR had shorter freedom from AVR than patients with moderate or severe acute AR but peak residual AS ≤35 mm Hg, although the difference between these groups did not reach significance (HR: 1.6; 95% CI: 0.89 to 2.9; p = 0.11).

Isolated native AS. Subgroup analysis of freedom from AVR and freedom from any aortic valve surgery was also
performed for the 320 patients in the present cohort with isolated native AS (i.e., no associated cardiovascular anomalies, no prior aortic valve interventions). Freedom from AVR among patients with isolated native AS was 94%/110061% at 5 years, 82%/110063% at 10 years, 68%/110064% at 15 years, and 57%/110065% at 20 years. Similar to the overall cohort, freedom from AVR and freedom from any aortic valve surgery among patients with isolated native AS were both longer in patients with lower post-dilation gradients and less severe post-dilation AR.

Discussion
In this long-term observational study, we followed 509 early survivors of balloon dilation for congenital AS for a median of 9.3 years and a maximum of 23.6 years. There was an ongoing steady hazard for AVR that was not associated with year or era of intervention, resulting in a freedom from AVR of 79%/110063% at 10 years and 55%/110064% at 20 years. Not surprisingly, acute post-dilation valve dysfunction, including both higher grade of AR and higher residual AS gradient,
were the strongest risk factors for eventual AVR and were independently associated with shorter freedom from AVR. These findings confirm that patients who undergo balloon dilation for AS, regardless of age, AS severity, or associated interventions, are at ongoing risk for AVR, a finding that should inform the clinical care of such patients before and after treatment of congenital AS. There was a steady hazard for death after a relatively steep acute phase hazard.

Risk factors for any aortic valve surgery were the same as for AVR on multivariate analysis, with the addition of multiple left-heart obstructive lesions and balloon dilation during the most recent quartile of our experience. Era was not a significant predictor of shorter freedom from aortic valve surgery on univariate analysis but was forced into the multivariate models in recognition of the changes in practice that inevitably occur over time. The finding on multivariate analysis that freedom from aortic valve surgery was shorter in the most recent quartile of patients undergoing balloon valvuloplasty is almost certainly due to a change in practice at our institution, with a more aggressive approach to aortic valve repair for AR over the past decade (16). No similar era effect was observed for AVR.

In this study, we included patients with congenital AS who underwent balloon dilation at any age, as long as it was performed at our center, as well as patients with associated cardiovascular anomalies and those who had undergone prior aortic valve intervention elsewhere. On univariate Cox regression analysis, isolated native AS, the absence of multiple left-heart obstructive lesions (2 of the following plus AS: aortic coarctation, mitral stenosis, subaortic stenosis), and no prior interventions for AS were associated with longer freedom from AVR and/or from any aortic valve surgery, but none of these variables were significant on multivariate analysis. In addition, in a subgroup analysis of the 320 patients with isolated native AS, there was only a modest overall difference in freedom from AVR or surgery compared

![Figure 5](image-url)
with patients with associated anomalies or prior interventions, and post-intervention AR and residual AS remained strong predictors of freedom from reoperation. Thus, although the findings in our overall cohort may be modestly confounded by the heterogeneity of the patient population, they reflect outcomes in the more limited subset of patients with isolated native AS, indicating that the long-term aortic valve outcomes are primarily a function of the underlying aortic valve disease and acute procedural outcomes.

The objective of this study was not to assess risk factors for acute outcome, which have been characterized in previous reports from our center and elsewhere (2,4,9–14). Nevertheless, we did observe that the incidence of moderate or severe AR was higher in patients who were older at the time of intervention and that there was no clear association between residual gradient and the severity of AR. Studies have shown that the risk for acute post-dilation AR is higher with larger balloon/annular diameter ratios, with a ratio of 0.9:1 to 1.0:1 an important threshold (2,4,11). However, other investigators whose practice did not include any procedures in which the balloon/annulus ratio exceeded 1.0:1 reported that below this threshold, the ratio was not associated with risk for AR (10). Other studies have suggested that aortic valve morphology, including the number of valve leaflets and valve thickness, may contribute to the risk for post-dilation AR as well (2,9). We and others have previously documented the tendency for AR to progress in severity over time after balloon dilation of congenital AS in neonates and older patients (10–12). Although the same analysis was not duplicated in this cohort, the ongoing hazard of aortic valve reoperation in this series supports that trend.

It is difficult to compare our findings with those of other recently published midterm to long-term follow-up studies of balloon dilation for congenital AS, such as those by Fratz et al. (12) and Reich et al. (9). Those studies included early deaths and analyzed reinterventions only as survival free from reintervention, neither of which was the case for our study. Because there is a well-known early hazard for death or conversion to single-ventricle circulation among newborns with AS, as well as improving early outcomes in this subset of patients in recent years (11), we elected to limit our study to early survivors to focus more clearly on the issue of aortic valve reintervention. Nevertheless, our findings do not seem markedly discrepant from the 5- to 10-year results reported by Fratz et al. (12) and Reich et al. (9) with respect to overall freedom from aortic valve reintervention. Pedra et al. (8) followed 87 children who underwent aortic valve dilation at ≥6 months of age for an average of 6.3 years and reported almost no mortality, 67% freedom from aortic valve reintervention at 5 years, and 46% freedom from reintervention at 12 years. Higher post-dilation gradient, significant post-dilation AR, and symmetric valve opening were associated with increased risk for aortic valve reintervention. Again, our findings are not dramatically different from those in that cohort.

In many respects, neonatal or critical AS is a different disease from congenital AS treated later in life. Clearly, the mortality risk is higher in newborns with symptomatic AS than in older infants, children, and adolescents or adults (9,12). We have previously reported acute and longer term outcomes in neonates treated with balloon aortic valvuloplasty (11,13) and did not explore that patient population in detail in this study. The primary reason for including neonates in this series was to assess the relative burden of reintervention over time, compared with patients who undergo dilation at an older age. Not surprisingly, we found that patients who underwent balloon dilation in the first month of life had a significantly higher hazard for repeat balloon dilation. As discussed in earlier reports, 1 of the top priorities in neonates with symptomatic AS is to provide sufficient relief of the left ventricular outflow obstruction to allow ventricular recovery and stable circulation, while avoiding severe AR. Thus, our tolerance for residual AS is relatively high in this cohort. Moreover, growth velocity is higher in newborns than older patients, and recurrent AS may be more likely to manifest in association with rapid patient growth. Despite the higher hazard for repeat balloon

**Table 5**

<table>
<thead>
<tr>
<th>Residual Peak AS Gradient (mm Hg)</th>
<th>Acute Post-Dilation AR</th>
<th>HR (95% CI)</th>
<th>p Value</th>
</tr>
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<tbody>
<tr>
<td>≤ 35</td>
<td>None-trivial</td>
<td>1.8 (0.99–3.2)</td>
<td>0.054</td>
</tr>
<tr>
<td></td>
<td>Mild</td>
<td>4.2 (2.3–7.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>&gt; 35</td>
<td>None-trivial</td>
<td>2.0 (1.1–4.0)</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>Mild</td>
<td>6.3 (3.5–11.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Moderate-severe</td>
<td>9.9 (4.8–20.4)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

AR = aortic regurgitation; AS = aortic stenosis; AVR = aortic valve replacement; CI = confidence interval; HR = hazard ratio.
dilation, patients initially treated for AS in the newborn period were at no higher risk for aortic valve surgery in general or AVR in particular than older patients.

A common and potentially important dilemma in patients undergoing balloon dilation for congenital AS at the time of the procedure is what balance to strike between residual AS and procedural AR. This question is particularly challenging when the gradient is between 30 and 40 mm Hg and there is trivial or mild AR. The balance of acute residual AS and AR after the procedure clearly has ramifications for future risk for aortic valve reintervention and AVR, but may take years to become manifest. Using a combined acute hemodynamic outcome variable, patients with residual AS gradients ≤35 mm Hg in general had longer freedom from AVR than those with gradients >35 mm Hg, and those with less significant AR had longer freedom from AVR than those with more severe AR. However, patients with residual AS gradients >35 mm Hg and only mild AR had shorter freedom from AVR than patients with less residual AS but more severe AR (p = 0.11), suggesting that reduction of AS below 35 mm Hg may be more important than previously recognized and may be indicated even at the expense of mild or greater AR. This analysis was not adjusted or stratified for age, and it is possible that the observed patterns do not hold true for particular age groups.

**Study limitations.** The primary limitations of this study were the retrospective study design and extended enrollment period, logistic considerations that may limit the applicability of our findings. Similarly, although there were general clinical guidelines, there were no standardized criteria for referral for catheterization or balloon dilation, or for defining a procedural end point, and practice likely varied over time and among practitioners. In analyses of freedom from reintervention, we considered only baseline and acute post-intervention variables and as such cannot account for the potential contributions of later developments or subacute or chronic changes in valve function or patient status. Also, many of the patients in this cohort were primarily followed elsewhere. Criteria for AVR or other reinterventions on the aortic valve may have varied within this population according to a variety of factors. Differences in clinical decision making around surgical reintervention in older and younger patients may have confounded our analysis. For instance, by univariate analysis, freedom from AVR was shorter in older patients. This may have been due in part to the higher incidence of significant acute AR in older patients (possibly due to operators’ being more aggressive in their attempts to relieve obstruction in this population, in whom AVR can be more readily undertaken than in younger patients) but also to a lower threshold for replacing the aortic valve in larger patients, in whom the risks of operation may be lower (17) and who are less likely to require reintervention for upsizing of the aortic valve prosthesis or, in the case of the Ross procedure, right ventricular outflow conduit (18). Also, for logistical reasons, we did not assess serial aortic valve function or the potential impact of evolving AR or outflow obstruction on freedom from reintervention. Because our primary focus was aortic valve reintervention, and certain questions relating to survival in this cohort are the focus of another ongoing study, our analysis of survival was limited.

**Conclusions**

Although balloon aortic valvuloplasty is highly effective for acute relief of congenital AS, there are steady long-term hazards for surgical aortic valve reintervention and for AVR that are independent of age at balloon dilation and severity of presenting AS. Although neonates are at higher risk for repeat balloon dilation, they are at no higher risk for AVR than older patients. These findings should inform counseling and evaluation of patients before and after treatment of congenital AS.

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**REFERENCES**


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