Annulus upsizing for mitral valve re-replacement in children

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Background: Mitral valve replacement remains the last resort for treatment of congenital mitral valve disease. Enlarging the mitral annulus at the time of mitral valve replacement may allow implantation of a larger prosthesis in children.

Methods: All mitral valve replacement procedures from 1990 to 2012 were included, and mitral annulus enlargement techniques were analyzed. A control group of patients undergoing replacement of a previously implanted mechanical mitral valve prosthesis was compared with the cohort of patients who underwent annular enlarging procedures. Primary end points were increases in annulus size and Z score, and freedom from paced rhythm.

Results: Among 205 mitral valve replacement procedures, 16 (8%) included techniques to upsize the mitral annulus in 15 patients, all but 1 of whom had undergone prior mitral valve replacement. These patients were compared with a control cohort of 53 patients undergoing mitral valve re-replacement without annulus enlargement. The annulus was upsized by $18\% \pm 11\%$ (compared with $16\% \pm 20\%$ in controls, $P = .5$) using open balloon dilation in 4 patients, radial annular incisions in 5 patients, and patch augmentation of the aorto-mitral continuity in 7 patients. The mean valvar diameter Z score increased from -0.2 ± 1.3 to $+1.1 \pm 1.4$ ($P < .001$), compared with an increase from -0.3 ± 1.2 to 0.9 ± 1.1 in controls ($P < .001$). During a mean follow-up of 6.5 ± 6.4 years, 4 of 12 patients required permanent pacing in the upsizing group (predominantly with patch augmentation), versus 5 of 53 patients in the control group.

Conclusions: In children undergoing mitral valve replacement, various techniques can be used to upsize the mitral annulus and allow implantation of a larger prosthesis. There is a nontrivial risk of heart block with annulus upsizing, which deserves further study. (J Thorac Cardiovasc Surg 2013;146:347-51)

Video clip is available online.

Mitral valve replacement (MVR) remains the last resort for treatment of congenital mitral valve disease in children, and it is especially challenging in infants with congenital mitral disease because of the small size of the native valve annulus, left atrium, and ventricle that predisposes them to complications related to leaflet entrapment, left ventricular outflow tract or pulmonary venous obstruction, and heart block.¹ Any mitral prosthesis placed in a child obligates reoperation to adjust for somatic growth, often prompting placement of as large a prosthesis as possible to delay patient-prosthesis mismatch as long as possible.² In infants, even the smallest

available mechanical prostheses are substantially oversized; supra-annular implant has been used to accommodate such mismatch, but this approach can be problematic for a number of reasons.^{3,4} Furthermore, an increased ratio of prosthetic valve size to patient weight was shown to be an independent age-adjusted predictor of death in the Pediatric Cardiac Care consortium report.⁵

Enlargement of a hypoplastic aortic annulus has been described with good results⁶⁻⁸; however, there are few reports of augmenting the mitral annulus.⁹ We report the techniques and outcomes of mitral annulus-enlarging procedures in children undergoing MVR over a 22-year period.

MATERIALS AND METHODS

Study Design

We reviewed all patients who underwent MVR between January 1990 and January 2012 at Children's Hospital Boston & Harvard Medical School by using a query of the cardiac surgery and cardiology databases. Operative notes were reviewed for techniques aimed at increasing the size of the mitral annulus. The study was approved by the Children's Hospital Institutional Review Board, and individual patient consent was waived. A control group of patients who underwent mitral valve re-replacement (reMVR) without annulus-enlarging procedures was used for comparison of baseline characteristics and outcomes.

The primary outcome measures were operative mortality, annulus size, and Z score increase and freedom from paced rhythm at latest follow-up. Secondary end points included valve-related complications, reoperations,

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Abbreviations and Acronyms

MVR = mitral valve replacement

reMVR = mitral valve re-replacement

and late mortality. Clinical or treatment variables were recorded to determine predictors of the end points. Because all measurements except for 1 involved a prosthetic valve, making echocardiographic measurements difficult, the prosthesis manufacturer-rated sizes for the prosthesis being removed and the prosthesis that was placed were used as approximations of mitral annular diameter before and after MVR, because measures of the mitral annulus were not systematically recorded in the operative notes. Z scores based on these measurements were calculated using normative equations for the mitral valve lateral diameter.

Statistical Analysis

Statistical analyses were performed with the Statistical Package for the Social Sciences (v 19, SPSS Inc, Chicago, Ill). Data are presented as mean $\pm$ standard deviation. Continuous variables were analyzed with the Student *t* test or the Wilcoxon signed-rank test when appropriate, and categorical variables were analyzed using the chi-square test or Fisher exact test when appropriate. Freedom from paced rhythm was calculated using the Kaplan-Meier method, and differences between curves were assessed by the log-rank test. Patients who were paced before the MVR operation included in the study were excluded from freedom from paced rhythm survival analysis. Data are presented as mean $\pm$ standard deviation, median (minimum-maximum), or frequency (%).

RESULTS

Demographics

Among 205 MVR procedures performed during the study period, 16 (8%) in 15 patients included additional techniques to upsize the mitral annulus to accommodate placement of a larger prosthesis. All but 1 of these patients had undergone prior MVR, and all had some form of mitral valve repair performed before MVR. A control group comprising 53 patients undergoing reMVR without annulus upsizing was compared with the study cohort. Patient baseline characteristics in the study and control groups are illustrated in Table 1. A majority of the patients had hypoplastic left heart structures, varying from hypoplastic left heart syndrome, Shone's complex, and unbalanced atrioventricular canal defects to congenital mitral stenosis. There were no statistically significant differences between the baseline characteristics in the study group and the controls. One of the patients who underwent mitral annulus augmentation was reported previously.⁹ All patients received a mechanical prosthesis (mostly from St Jude Medical Inc, St Paul, Minn), with the exception of 2 who received a bioprosthetic valve (1 each in the study and control groups, a Hancock valve [Medtronic, Minneapolis, Minn] and a Melody valve [Medtronic], respectively).

Mitral Annulus Upsizing

In the annulus upsizing group, the annulus was increased from a median diameter of 19 mm (12-23 mm; mean,

18.8 $\pm$ 2.5 mm) to 22 mm (16-27 mm; mean, 22.1 $\pm$ 3 mm, $P < .001$) and a mean Z score of -0.16 ± 1.28 to $+1.12 \pm 1.42$ ($P < .001$). The decision to perform additional procedures for annulus upsizing was based on the surgeon's intraoperative decision to permit implantation of a larger prosthesis compared with the one being explanted. The mean annular dimensions before and after MVR are summarized in Table 2; annulus upsizing was performed using open balloon dilation with or without radial incisions in the annulus in 4 patients (techniques detailed in Table 3; see Video 1 for illustration of the technique), 5 patients had radial annular incisions without additional annulus-enlarging procedures, and 6 patients had patch augmentation of the aorto-mitral continuity in 7 operations, following Nicks' technique in 1, Manouagian technique in 2, and modified Manouagian technique⁹ in 4. The changes in valve diameter and Z score did not differ significantly between annulus-upsizing techniques.

In the control group, the annulus was upsized at reMVR from a median of 19 mm (16-31 mm; mean, 20.1 $\pm$ 3.4 mm) to 23 mm (16-35 mm; mean, 23.5 $\pm$ 3.6 mm, $P < .001$), which was an increase in the Z score from -0.31 ± 1.17 to $+0.94 \pm 1.13$ ($P < .001$). There were no significant differences in final valve diameter or Z score between the annulus upsizing and control groups ($P = .6$ and $P = .1$, respectively).

Outcomes

There were 2 operative deaths due to severe left ventricular failure after mitral and aortic valve replacement with Manouagian annulus augmentation, which were both in the early period of the study (1990 and 1991). The postmortem examination found well-functioning prostheses and intact coronaries in 1 patient, and a paravalvar mitral leak and proximal right coronary artery occlusion by an aortic valve prosthesis leaflet stuck in the open position in 1 patient. There were no other ischemic, bleeding, or thromboembolic complications due to these additional procedures.

During a mean follow-up of 6.5 $\pm$ 6.4 years, 4 patients in the annulus upsizing group and 5 patients in the control group required new permanent pacemaker implantation. As shown in Figure 1, freedom from a new paced rhythm after MVR (ie, excluding patients with existing pacemakers) was 86% $\pm$ 10% at 1 year, 73% $\pm$ 14% at 3 years, and 59% $\pm$ 17% at 5 years in the annulus upsizing group, compared with 88% $\pm$ 5% at 1, 5, and 10 years in the control group ($P = .15$). One patient who underwent both radial annular incisions and balloon dilation developed postoperative complete heart block and required transvenous pacemaker implantation 10 days after MVR. This patient returned to normal sinus rhythm by 3 months postoperatively and was no longer in a paced rhythm at most recent follow-up (4 months after MVR). Acute postoperative complete heart block developed in 4 patients with anterior

TABLE 1. Baseline characteristics of study patients and controls

	Annulus upsizing group (n = 16)	reMVR controls (n = 53)	P
Age (y)	10.8 ± 6.2	14.1 ± 9.2	.1
BSA (m ²)	0.97 ± 0.38	1.16 ± 0.44	.1
Male	10 (63%)	28 (53%)	.6
Reason for MVR			
Shone's complex	5 (31%)	11 (21%)	.5
Congenital mitral stenosis	4 (25%)	15 (28%)	1
Common atrioventricular canal defect	4 (25%)	21 (40%)	.4
Borderline hypoplastic left heart syndrome	1 (6%)	0 (0%)	.2
Endocarditis	1 (6%)	1 (2%)	.4
Other	1 (6%)	5 (9%)	1
Prior procedures			
Mitral balloon valvuloplasty	0 (0%)	7 (13%)	.2
Surgical mitral valvuloplasty	10 (63%)	19 (36%)	.08
MVR	15 (94%)	53 (100%)	.2
reMVR	3 (19%)	23 (43%)	.09
Fetal aortic balloon valvuloplasty	1 (6%)	0 (0%)	.2
Aortic balloon valvuloplasty	1 (6%)	4 (8%)	1
Aortic valve repair	2 (13%)	5 (9%)	.7
Aortic valve replacement	2 (13%)	1 (2%)	.1
Atrioventricular canal defect repair	4 (25%)	21 (40%)	.4
Left ventricular EFE resection	1 (6%)	0 (%)	.2
Subaortic stenosis repair	6 (38%)	15 (28%)	.5
Coarctation repair	4 (25%)	12 (23%)	1
Permanent pacemaker implantation	1 (6%)	11 (21%)	.2
Other procedures	6 (38%)	21 (40%)	1
Native mitral annulus diameter (mm)	18.8 ± 2.5	20.1 ± 3.4	.1
Native mitral annulus diameter Z score	−0.16 ± 1.28	−0.29 ± 1.16	.7

All values are reported as mean ± standard deviation or number (percentage) unless otherwise indicated. *reMVR*, Mitral valve re-replacement; *BSA*, body surface area; *MVR*, mitral valve replacement; *EFE*, endocardial fibroelastosis.

annulus patch augmentation; 2 were the operative deaths mentioned earlier and 2 underwent pacemaker implantation 6 and 8 days after MVR, respectively. One patient who underwent annulus enlargement with radial annular incisions

had first-degree atrioventricular block in the immediate postoperative period, but this progressed to complete heart block by 2.8 years postoperatively, at which point transvenous pacemaker implantation was performed.

Two patients in the study group underwent an additional reMVR, both in conjunction with aortic valve replacement. One of these patients underwent Manouagian mitral annulus augmentation at the time of redo MVR, and the other did not have further annulus augmentation. There was 1 noncardiac late death, and 1 patient died of perioperative stroke after a reoperation for aortic valve replacement and reMVR.

DISCUSSION

MVR in children remains a last resort to a difficult problem. In children with a small or hypoplastic native mitral annulus, implantation of commercially available prosthetic valves can be problematic. Supra-annular prosthesis implantation has been proposed when annular implantation is not possible, but early results have been discouraging, with high mortality and the risk of left atrial diastolic dysfunction and pulmonary vein stenosis,¹⁰⁻¹² although more recent reports have shown good results.⁴ Furthermore, supra-annular MVR does not protect against leaflet entrapment or valve thrombosis, which occurred in 13% of the patients with supra-annular MVR reported by Kanter and colleagues.⁴

In some children, even supra-annular implantation does not allow placement of a large enough prosthesis. Much as with aortic valve replacement in a small aortic root, the options in this situation are to place a smaller prosthesis, risking earlier patient–prosthesis mismatch, or to increase the size of the native mitral annulus.⁶⁻⁸ Methods of increasing the size of the native mitral annulus have been seldom reported,⁹ because at the time of reMVR, the prosthesis usually can be upsized by 2 sizes on average.¹³

In our experience with MVR, 8% of procedures have included a technique to upsize the mitral annulus at MVR to permit upsizing of the new prosthesis. This has included a variety of techniques, including intraoperative balloon dilation of the annulus under direct vision, radial annular incisions, and patch augmentation of the aorto-mitral continuity. By using these techniques, it was possible to enlarge the annulus by approximately 2 mm on average and to place

TABLE 2. Mitral annulus-upsizing techniques and results

Technique	N	Native annulus diameter (mm)	Z score	Final annulus diameter (mm)	Z score	Mitral annulus diameter increase	Z score increase
Balloon dilatation +/- radial annular incisions	4	18 ± 4.2	−0.39 ± 0.43	21.3 ± 4.8	0.96 ± 0.82	19.3% ± 13.8%	1.36 ± 1.1
Radial annular incisions	5	18.8 ± 1.5	−0.15 ± 2.1	23 ± 3.2	1.3 ± 2.1	22.1% ± 11.7%	1.41 ± 0.42
Aorto-mitral continuity patch augmentation	7	19.1 ± 2.2	−0.03 ± 0.98	21.9 ± 2.0	1.11 ± 1.30	14.6% ± 7.7%	1.13 ± 0.60

All values are reported as mean ± standard deviation or number (percentage) unless otherwise indicated.

TABLE 3. Intraoperative balloon dilation for enlarging the mitral annulus

Technique	Native annulus diameter (mm)	Z score	Final annulus diameter (mm)	Z score	Increase in mitral annulus diameter (%)
Radial annular incisions, 22-mm balloon at 12 and 30 Atm	21	−0.47	23	0.16	10%
Radial annular incisions, 18-mm high-pressure balloon	18	0.09	19	0.36	6%
26-mm balloon at 4 Atm	21	−0.25	27	1.76	29%
14-mm balloon at 4 Atm, 16 mm balloon at 2 Atm	12	−0.94	16	1.59	33%

Atm, Atmospheres.

a prosthesis of similar size in patients undergoing reMVR who did not require annulus enlargement.

More patients in the annulus upsizing group required permanent pacing than in the reMVR group, although this

difference did not reach statistical significance. The prevalence of postoperative heart block or pacemaker implantation is nontrivial after MVR in children, ranging from 6% to 33%.^{1,3,14} Supra-annular implantation has not been proven to protect from pacemaker requirement, with a reported prevalence of pacemaker implantation after primary supra-annular MVR of 21%⁴ and additional risk at the time of the inevitable reMVR.³ In our experience with annulus upsizing at MVR, 4 patients required new pacemaker implantation and long-term pacing, including 3 who underwent a Manouagian patch augmentation of the aorto-mitral continuity and 1 who underwent radial annular incisions, and none who underwent intraoperative balloon dilation. Although the difference in this outcome between techniques was not significant, given the limited number of patients, all but 1 of the patients with long-term pacing underwent a Manouagian annulus augmentation. This technique involves a Guiraudon-type superior trans-septal approach to the mitral valve, which requires division of the sinus node artery and anterior internodal pathway, and depending on the location of the atriotomy and septal incision may also place the middle and posterior internodal pathways at risk.¹⁵

Study Limitations

This study has several limitations. It is a retrospective and nonrandomized comparison of techniques to upsize the mitral annulus and represents a 22-year period of evolving experience with MVR. As such, any inferences drawn from these data are limited by confounding variables that are differently distributed between study groups, such as associated lesions, degree of hypoplasia of the left heart structures, and duration of follow-up. Given the long study period, there is the potential for changes in management practices. Our sample size also limits our ability to perform extensive statistical adjustments for these differences. The choice to use an annulus-upsizing technique was at the discretion of the operating surgeon, as was the specific technique used, introducing the risk of selection bias. We have no control group of patients in whom the annulus was not upsized and a smaller prosthesis was placed. Nonetheless, this represents the largest series of annulus-upsizing procedures and analyzes the specific risk of permanent pacing after such procedures.

CONCLUSIONS

After MVR in childhood, it has been reported that a mitral prosthesis can be upsized by an average of 2 sizes at the time of re-replacement.^{2,3,13} As illustrated in this report, additional techniques can be used successfully to upsize an annulus that is hypoplastic because of the intrinsic disease or inadequate growth, but such procedures carry a nontrivial risk of heart block. These techniques should

FIGURE 1. Kaplan-Meier analysis of freedom from paced rhythm, comparing the annulus upsizing group with the reMVR group. Twelve patients were excluded from the freedom from paced rhythm survival analysis because of prior pacemaker insertion, 1 (6%) in the annulus upsizing group and 11 (21%) in the reMVR group. MVR, Mitral valve replacement; reMVR, mitral valve re-replacement.

be considered as an additional surgical tool for MVR in children.

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