Long-term results of a strategy of aortic valve repair in the pediatric population

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Objectives: To determine rate of reoperation subsequent to primary valve repair in a pediatric population.

Methods: Between 1996 and 2009, 142 consecutive patients underwent aortic valve repair in our institution. Median age at surgery was 9 years, with 30 being younger than age 1 year. Indication for surgery was stenosis (n = 76), regurgitation (n = 55), and both (n = 11). Forty-six patients underwent repair with no addition of patch, whereas 96 patients required addition of patches of glutaraldehyde preserved autologous pericardium for cusp extension (n = 51) and other repair (n = 45).

Results: In the early postoperative period after cusp extension repair, 2 patients had a sudden unexplained death and 1 had cardiac arrest requiring mechanical support and heart transplantation. Two additional patients with cusp extension displayed signs of coronary ischemia. After a mean follow-up of 3.4 ± 3.5 years, only 1 patient died of a noncardiac cause. Seven-year freedom from reoperation was 80% (95% confidence interval [CI], 66-89). By multivariate analysis, the only predictors of reintervention were cusp extension (hazard ratio [HR], 5.4; 95% CI, 1.7-16.8; $P = .004$) and infants (HR, 5.6; 95% CI, 1.7-18.4; $P = .005$). At final echocardiography follow-up, 23 of 119 survivors without reoperation had moderate (19%), 1 had moderate-severe (1%), and 1 had severe regurgitation (1%), whereas 12 (10%) had a moderate degree of stenosis.

Conclusions: Aortic valve repair in pediatric populations is effective in postponing reintervention. The longevity of the repair is shorter after cusp extension and when performed in infants. Caution should be used when performing tricuspidization and cusp extension of bicuspid valves because it can be responsible for mortality related to occlusion of the coronary ostia by patches. (J Thorac Cardiovasc Surg 2013;145:461-9)

During the past 3 decades, decision making in aortic valve disease for pediatric populations has been influenced by the emergence of new techniques, but long-term outcomes have been difficult to compare.¹ In the mid-1980s, techniques of aortic balloon valvuloplasty were developed.^{1,2} This field saw a rapid expansion and it seems that interventional catheterization is today the primary treatment modality in most centers worldwide.³ In the best hands, this procedure can yield a freedom from reintervention of up to 50% for around 10 years in children and adolescents.⁴ Today the American College of Cardiology/American Heart

Association guidelines⁵ preclude the use of balloon valvuloplasty in adults, but it remains a standard treatment in children and adolescents. The Ross procedure was popularized in the mid-1990s, and it is only recently that we gained perspective on the longevity of this procedure.^{6,7} Disappointingly, because of the progressive dilatation of pulmonary autografts, a quarter of these patients may require reintervention on the autograft within 2 decades of the procedure. It is yet unclear if these results of the Ross procedure will be similar or worse in a pediatric population because all published series have reported outcomes in a mixed population of children and young adults. Some techniques of surgical valvuloplasty have existed for many years, but this field has only known its real expansion in the past decade, after the adult techniques of valve repair were better delineated.⁸ Only some isolated reports of valve repair with cusp extension in a pediatric population have been published and it remains difficult to evaluate the indications of aortic valve repair in the armamentarium of the available techniques.⁹⁻¹¹

During the past decades, our center has progressively adopted a policy favoring primary aortic valve repair in pediatric patients with aortic valve disease. We decided to investigate the long-term outcomes of this policy to determine its efficacy in terms of survival and freedom from reoperation.

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FIGURE 1. Aortic valve procedures.

PATIENTS AND METHODS

The design of the study was approved by the local Human Research Ethics Committee and the need for consent was waived because of the retrospective nature of the study. The files of all patients undergoing an aortic valve repair at the Royal Children's Hospital, Melbourne, were reviewed. The aim of the study was to determine outcomes of contemporary techniques of aortic valve repair in a biventricular circulation and, therefore, patients undergoing single ventricle palliation were excluded. Between 1996 and 2009, a total of 239 patients underwent an aortic valve procedure. The 19 patients whose surgery was limited to a simple commissurotomy, and the 21 affected by rheumatic heart disease whose outcomes may depend on their underlying disease, were excluded. Over the same time period, 57 patients underwent primary balloon valvuloplasty, 97 underwent a Ross procedure, and 142 underwent an aortic valve repair (Figure 1). During the initial period, surgery and catheter interventions were offered concomitantly and progressively, and patients were preferentially referred to surgery. Patients were considered candidates for an aortic valve repair if the hinge point of the leaflets was still mobile, notwithstanding the amount of fibrosis found on the remaining leaflets. All nodular fibrosis was resected, and if the amount of remnant leaflet tissue did preclude a repair with a minimal use of patches, a cusp extension technique was used. The 142 consecutive patients who successfully underwent an aortic valve repair in our institution (38 girls, 104 boys) constitute the core of this study.

The median age at time of aortic valve repair was 9 years (range, 0-20 years). Thirteen of these were neonates (age ≤ 30 days), 17 were infants (age range, 31-267 days), 101 were aged between 1 and 18 years, and 11 were older than age 18 years.

The etiology of valve disease was congenital in 138 patients (97%) and endocarditis in 4 patients. The primary indication for surgery was aortic insufficiency in 55 patients, aortic stenosis in 76 patients, and mixed aortic stenosis and insufficiency in 11 patients. Table 1 displays the primary indication for surgery by age group.

Forty-five patients had a prior cardiac intervention. Among those, 27 patients (19%) had a previous intervention on the aortic valve: 10 had a previous commissurotomy, and 17 had a balloon valvuloplasty. Additional previous cardiac procedures were coarctation repair ($n = 8$), ventricular septal defect closure ($n = 6$), relief of left ventricular outflow tract obstruction ($n = 5$), aortic arch repair ($n = 2$), and arterial switch operation ($n = 1$).

Thirty-nine patients had an additional 48 procedures performed concomitantly to the valve repair: ventricular septal defect closure ($n = 17$), relief of left ventricular outflow tract obstruction ($n = 16$), aortic arch repair ($n = 6$), mitral valve repair ($n = 4$), partial anomalous pulmonary valve drainage repair ($n = 1$), relief of supra-aortic stenosis ($n = 2$), postswitch repositioning of a coronary artery ($n = 1$), and pulmonary valve repair ($n = 1$). Cardiopulmonary bypass and crossclamp times were 119 ± 42 minutes and 86 ± 33 minutes, respectively.

The aortic valve was unicuspid in 7 patients, bicuspid in 87 patients, and tricuspid in 48 patients. The 7 patients with a unicuspid valve underwent a re-creation of neocommissures with pericardial patches. Thirty-five of the 87 bicuspid valves were made tricuspid and 52 were left bicuspid. Fifty-one patients had a cusp extension performed. Out of these, 3 patients had extension of 1 cusp, 7 patients had extension of 2 cusps, and the remaining 41 had extension of three cusps. Thirty-three patients had a tricuspidization of a bicuspid valve with an extension of the 3 re-created cusps. Forty-five patients had use of pericardial patch material for a purpose other than cusp extension. In 17 patients, these patches were used to repair a perforation in the cusp and in 28 patients patches were used to re-create a single neocommissure (including 3 unicuspid valves). The remaining 46 patients underwent repair without addition of any pericardial patch material. They had a total of 62 procedures performed: commissurotomy and extensive resection of nodular dysplasia and thinning of leaflets ($n = 26$), triangular resection of free edge ($n = 19$), subcommissural annuloplasty ($n = 7$), free edge plication ($n = 8$), and repair of perforated leaflet using interrupted suture ($n = 2$). Our surgical techniques have been previously described.¹² All patches used were made of autologous pericardium treated with 0.625% glutaraldehyde. The patches were treated in a dish with a lid allowing the pericardium to be maintained flat and were subjected to a first bath of 2 minutes. The lid was then removed and the pericardium was turned over and treated for an additional 6 minutes. Over the course of the study, the second exposure to glutaraldehyde was reduced to 2 minutes. The patches were then rinsed 3 times for 3 minutes in normal saline. In the final rinse, 960 mg magnesium chloride was added per liter of normal saline. The patches were cut in equal rectangular shapes for symmetric tricuspid valves, and adapted to the need for asymmetrical valves. The height of the patch was not estimated in a standard fashion, but was left to the individual surgeon's discretion. All patients undergoing a repair were anticoagulated with 5 mg/kg aspirin for the first 2 postoperative months.

TABLE 1. Primary indication for surgery by age group*

	Neonates and infants	Noninfants	Total
AS	29 (97)	47 (42)	76
AI	1 (3)	54 (48)	55
AS/AI	0 (0)	11 (10)	11
Total	30	112	142

Data are presented as n (%). AS, Aortic stenosis; AI, aortic insufficiency. *Neonates and infants were considered children aged 1 year and younger. Noninfants were children aged 1 year or older.

Hospital mortality was defined as death before hospital discharge or within 30 days of the surgery. Late mortality was defined as death after discharge or >30 days from the first valve operation. Early reinterventions were defined as any operation on a previous valve repair or replacement before hospital discharge and were considered separate to late reoperations occurring after hospital discharge. Reporting of valve-related outcomes, such as valve thrombosis and bleeding events, were based on published guidelines.¹³

Follow-up information was gathered from the hospital database or collected from their referring cardiologists.

Statistical Analysis

Statistical analysis was performed using Stata 10 (StataCorp, College Station, Tex). Parametric data were expressed as mean ± standard deviation and median (interquartile range). All tests of a patient’s characteristics were 2-tailed. Risk factors for time-related outcomes such as late mortality, reintervention, and valve replacement were tested from the date of first valve surgery using Cox regression analysis. All pre- and perioperative variables were tested for their association with reintervention and valve replacement (Table 2). Univariate analysis identified variables most likely to be associated with the given event, which were then entered in a stepwise fashion into multivariate analysis.

TABLE 2. List of parameters

Parameter	Freedom from reintervention			Freedom from valve replacement		
	P value	HR	95% CI	P value	HR	95% CI
Sex	.948	1.04	0.34-3.14	.721	0.81	0.25-2.64
Indication						
Aortic regurgitation	.971	0.98	0.36-2.71	.865	1.09	0.39-3.07
Aortic stenosis	.806	1.13	0.42-3.06	.994	1	0.36-2.78
Mixed aortic stenosis/aortic regurgitation	.633	0.66	0.08-5.48	.748	0.71	0.09-5.89
Concomitant cardiac procedure	.256	0.48	0.13-1.75	.132	0.31	0.07-1.42
Previous cardiac surgery	.963	1.03	0.36-2.93	.82	1.13	0.39-3.28
Age at surgery (d)	.229	0.99	0.99-1.00	.38	0.99	0.99-1.00
Age <1 y at time of surgery	.048	2.89	1.00-8.3	.122	2.37	0.79-7.08
Cusp extension technique	.020	3.34	1.20-9.29	.011	3.95	1.36-11.5
Use of patch (excluding cusp extension)	.231	2.82	0.52-15.4	.377	2.2	0.38-12.7
Initial valve morphology						
Unicuspid valve	.908	1.14	0.13-10.0	.859	1.21	0.14-10.8
Bicuspid valve	.581	1.34	0.47-3.82	.377	1.64	0.54-4.96
Tricuspid valve	.535	0.71	0.24-2.11	.324	0.55	0.17-1.80
Body surface area	.229	0.56	0.22-1.44	.098	0.43	0.15-1.17
Crossclamp time	.344	1.01	0.99-1.02	.344	1	0.99-1.02
Bypass time	.087	1.01	0.99-1.02	.087	1.01	0.99-1.02
Significant regurgitation before surgery	.260	1.78	0.65-4.81	.388	1.57	0.57-4.33
Significant stenosis before surgery	.887	0.93	0.35-2.46	.717	0.83	0.31-2.25
Mean peak gradient before surgery	.847	1.03	0.74-1.44	.858	1.03	0.73-1.45

Boldface types indicates values reaching a P value < .05 by univariate (freedom from valve replacement) and multivariate (freedom from reintervention) analysis. HR, Hazard ratio; CI, confidence interval.

RESULTS

There were 3 early deaths (2%). Two deaths occurred suddenly after hospital discharge, 4 and 17 days after repair in a 7-year old and a 14-year old diabetic, respectively, both of whom had undergone a cusp extension technique. The third death occurred in a neonate with poor ventricular function 10 days postoperatively due to extensive brain damage most likely related to an embolus occurring during his postoperative mechanical support.

An additional 3 patients developed postoperative signs of myocardial ischemia after cusp extensions. One patient experienced sudden cardiac arrest on his first postoperative day in the intensive care unit. Extracorporeal membrane oxygenation was instituted under cardiopulmonary resuscitation with central cannulation via sternotomy and 9 days later, a Thoratec paracorporeal ventricular assist system (Thoratec Corp, Pleasanton, Calif) was inserted. After 58 days of support, he underwent an orthotopic heart transplantation. One 3-year old patient had recurrent electrocardiographic signs of ischemia, without clinical symptoms. The electrocardiographic changes subsided spontaneously after hospital discharge. The final patient who underwent a tricuspidisation of a bicuspid valve with cusp extension suffered intractable ventricular fibrillation after removal of the cross-clamp. Transoesophageal echocardiography raised the suspicion of the interference of the left main coronary ostium with its extended cusp. The aortic valve was exposed, the cusp facing the left main coronary orifice was slightly

FIGURE 2. Perioperative imaging by transoesophageal echocardiography with illustration. A, Bicuspid aortic valve. B, Tricuspidization with cusp extension resulting in the prolapse of the leaflet patch on the coronary ostium. C, After trimming of the left coronary cusp and resuspension of the facing commissure between the right and the noncoronary cusp the coaptation of the 3 leaflets is displaced centrally relieving ostial occlusion. LCA, Left coronary artery.

trimmed, and the facing re-created commissure between the noncoronary and the right coronary cusp was resuspended to displace centrally the coaptation point between the three leaflets (Figure 2). The patient subsequently showed no more signs of ischemia. Following this event, we reviewed the operative details and all echocardiographic examinations of the 3 cases showing postoperative signs of ischemia and the 2 patients who experienced sudden death. All patients had tricuspidisation of a bicuspid valve with cusp extension. An exact mechanism leading to myocardial ischemia could not be identified, but interference of the patches with the coronary orifices could not be ruled out.

There was 1 early reintervention on the aortic valve during the same hospital stay. One neonate remained in the hospital with poor ventricular function and required a Ross procedure 2 months after his initial valve repair. One patient required a chest reexploration for bleeding, 1 experienced a complete heart block and required a pacemaker implantation, and 1 patient experienced a pulmonary hemorrhage and a stroke with complete recovery.

The mean follow-up in hospital survivors was 3.4 ± 3.5 years and extended to 14 years. Only 2 patients were lost to follow-up and completeness of follow-up was 99%. Concurrent (2008-2011) completion of follow-up was 80%

(114 out of 142). One patient aged 21 years died in a motor vehicle accident 6 years after his valve repair. Survival at 1 and 10 years were, respectively, 98% (95% confidence interval [CI], 93%-99%) and 95% (95% CI, 82%-98%). No subsequent neurologic or thromboembolic events were reported during follow-up.

Freedom From Reintervention

Eighteen patients had a late reintervention after a median of 3.6 years (range, 1-7 years). Eleven were Ross procedures, 3 had a mechanical valve replacement, 3 had a re-repair, and 1 underwent a Bentall procedure. The indications for reintervention were aortic stenosis in 8 patients, insufficiency in 6 patients, endocarditis in 2 patients, and mixed stenosis and regurgitation in 2 patients. Two patients underwent a Ross procedure 5 and 6 years, respectively, after these reinterventions.

Freedom from reintervention at 1, 5, and 7 years, respectively, were 97% (95% CI, 92%-98%), 87% (95% CI, 76%-93%), and 80% (95% CI, 66%-89%) (Figure 3, A). Multivariate analysis identified the following predictors for reintervention: cusp extension technique (hazard ratio [HR], 5.4; 95% CI, 1.7-16.8; $P = .004$) and being younger than age 1 year at time of repair (HR, 5.6; 95% CI, 1.7-18.4; $P = .005$) (Table 2). The freedom from reintervention was $90\% \pm 5\%$ (95% CI, 75%-96%) at 7 years for those who had no cusp extension, compared with $66\% \pm 11\%$ (95% CI, 40%-83%) at 7 years for those who had a cusp extension (Figure 3, B).

Freedom From Valve Replacement

Seventeen patients underwent a valve replacement. The mean interval between initial repair and valve replacement was 6 ± 4 years. The freedom from valve replacement was $81\% \pm 6\%$ (95% CI, 65-90) at 7 years (Figure 3, C). Univariate analysis identified having a cusp extension (HR, 3.9; 95% CI, 1.3-11.4; $P = .011$) as the only predictor of having a future valve replacement (Table 2).

Late Valvular Function

At final follow-up, 119 patients were surviving with their native valve. Twenty-three had moderate regurgitation, 1 had moderate to severe regurgitation, and 1 had severe aortic valve regurgitation. Twelve patients were described as having moderate stenosis or more and had an average peak gradient of 66 ± 18 mm Hg. The average peak gradient of the remaining 107 patients without stenosis was 21 ± 13 mm Hg.

DISCUSSION

The place of aortic valve repair in the armamentarium of techniques to treat aortic valve disease in children is still unclear. Historical series have demonstrated that balloon valvuloplasty achieves similar results to surgery in terms

FIGURE 3. Late outcomes. A, Kaplan-Meier freedom from reintervention. B, Kaplan-Meier freedom from reintervention in those with and without cusp extension. C, Kaplan-Meier freedom from valve replacement.

of survival and reoperation rate. These comparisons no longer seem valid because the development of techniques of valve repair started only in the mid-1990s after these comparative studies were completed. In recent years, there has been a drop in enthusiasm for the Ross procedure, a technique that was initially promised to become the best option in the pediatric age group.^{7,14,15} Recent follow-up studies confirmed that at least one-quarter of the autografts would fail in the first 20 years following the Ross procedure, most of them because of the progressive dilatation of the autograft.^{6,7} These alarming results may be improved by the use of the inclusion technique, but this latter technique is rarely possible in children.¹⁶ Six years after the classic technique of root replacement in the pediatric population, 97% of patients were found to have an autograft root size z score >4 .⁷ The current reports of outcomes of aortic valve repair in children have mainly been limited to series of cusp extension, mainly in patients with rheumatic disease, and it has been difficult to establish the benefits of a policy of aortic valve repair adopting all available techniques.^{9,10}

Our experience favoring valve repair over balloon dilatation and Ross procedure gives insights to the outcomes achievable by this approach. It was not our goal to achieve a definitive repair in this population, but rather to postpone valve replacement for as long as possible. As a result of this policy, close to two-thirds of our patients remained free of reintervention for up to 9 years. The patients undergoing addition of glutaraldehyde preserved autologous pericardium seemed to be subjected to a constant rate of reoperation and our study seems to confirm that all patients will ultimately require a reintervention by 12 to 15 years. Interestingly, our experience with cusp extension in congenital aortic valve disease seems to match the experience reported by the team working in Riyadh, Saudi Arabia,⁹ with the same technique in rheumatic aortic valve disease. It has now been reported that up to 80% of adults undergoing repair without addition of patch material may remain free of reintervention for a decade and, hopefully, a large proportion of these patients will have long-lasting results.⁸ The use of these techniques in children seems to be superior to the results of cusp extension and we therefore believe that aortic valve repair without patch material should be favored, if feasible. Similar to the adult population, these techniques of repair are mainly restricted to aortic regurgitation. Neonates, infants, and small children present mainly with congenital aortic stenosis with typically small aortic roots necessitating a maximal enlargement of the effective orifice area. In our experience, opening of unicuspid valves into bicuspid valves and the tricuspidization of bicuspid valves is necessary in these patients. The cusp extension technique has been unavoidable in some of these cases. In recent times, we have tried to avoid this technique by performing alternate techniques such as resection of a fused

commissure and recreation of a new commissure with triangular patches or triangular resection of a raphe and patch reconstruction of the defect.

Because patients were progressively preferentially referred to surgery, aortic balloon valvuloplasty has been virtually abandoned in our center and we can no longer compare the results of aortic valve repair with this technique in a contemporary era. It appears, however, that our overall results with valve repair are superior or at least equivalent to best practices of balloon valvuloplasty.³ Although the freedom of reoperation of our patients is not by far superior to balloon valvuloplasty, only a fraction of them have required valve replacement, and we hope to have ultimately a larger proportion of patients who will not require any further reoperation. We also believe that primary repair will maintain the best quality of aortic valve tissue giving better chances of a longer lasting repair. However, most of the patients on whom we operate at a young age will ultimately require valve replacement. By performing a repair at young age, we hope to obtain growth of their aortic root and to postpone the Ross procedure to a time when they have reached a size allowing the use of techniques preventing subsequent autograft root dilatation.^{17,18}

Although the overall results of this policy of aortic valve repair in children has been satisfactory, we have been concerned by the ischemic complications that some of these patients developed after tricuspidisation and cusp extension. It is only recently that we have been able to demonstrate that the mechanism of this ischemia may be related to the obstruction of 1 coronary ostium by the bulk of the patches. With increasing experience with the cusp extension technique, one often tends to use high patches to achieve reliable valve competence. These patches do not seem to cause obstruction of the coronary ostia in symmetric tricuspid valves, but may become obstructive in bicuspid valves made tricuspid.

Tricuspidisation often results in the creation of a smaller cusp. We believe that, in this instance, the coaptation point of the 3 newly re-created leaflets may occur close to the aortic wall, and that the edge of the patch facing this small cusp may flick toward the wall and occlude the coronary ostium. It has not been possible to prove retrospectively that this mechanism was the cause for the 3 dramatic events observed in this series. Sudden death has been shown to occur even after balloon valvuloplasty and other mechanisms may have been responsible for the sudden deaths observed.¹⁹ We believe that surgeons should use ultimate caution when performing tricuspidization and cusp extension in patients with bicuspid valve, and pay a particular attention not to use patches that are too high and may become redundant. We hope that a raised awareness toward ischemic complications may prevent the occurrence of these adverse events. Up to this stage, simpler procedures do not seem to warrant better outcomes, but this finding may be related to the limited number of patients in this series.

Limitations

At the beginning of our study period patients were offered either balloon valvuloplasty or surgery, thereby possibly constituting a selection bias. Accordingly, a large number of patients were operated in recent times, restricting the number of available data for long-term follow-up.

CONCLUSIONS

A policy of aortic valve repair in pediatric populations is effective in postponing reintervention. The longevity of the repair is shorter after cusp extension and when performed in infants. Caution should be used when performing tricuspidization and cusp extension of bicuspid valves because it can be responsible for mortality related to occlusion of the coronary ostia by patches.

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Discussion

Dr Kristine Guleserian (Dallas, Tex). Let me start by congratulating you and Dr Brizard and the rest of the Melbourne group for the excellent presentation and the very well-written manuscript that I had a chance to review before this presentation of your experience over the past 13 years with 142 patients. Thirty of those patients were less than a year of age, and 13 were neonates who had undergone aortic valve repair with 80% freedom from reintervention at 7 years, and two-thirds—or 66%—with freedom from intervention at 9 years.

This is certainly a challenging group of patients for whom we all would like to provide a very durable and safe repair to help delay subsequent reintervention, whether it's re-repair; Ross procedure; aortic valve replacement; or, in rare instances, cardiac transplantation. And of course, primary aortic valve repair is always favorable with a goal to recapitulate normal aortic anatomy and physiology; however, this is not always possible, and cusp extension or leaflet extension procedures often, along with tricuspidization, are required.

Drs Polimenakos, Ilbawi, and the Chicago group published their results with aortic cusp extension using selective tricuspidization in infants and children with actuarial freedom from reintervention of 97%, 71%, and 56% at 1, 5, and 10 years. So those are pretty similar.

And Dr Bacha and the Boston group have shown very good intermediate results with surgical aortic valvuloplasty, 80% of which incorporated pericardial cusp extension for children and adolescents with aortic insufficiency and no more than really moderate aortic stenosis with freedom from intervention of 72% at 5 years and 54% at 7.5 years.

In your presentation you point out the potential shortcomings of cusp extension with respect to the shorter longevity of repair, particularly in the infant subgroup, and the development of what we are calling presumed myocardial ischemia in the subset of patients with the adverse events that you just outlined. You therefore urge caution when employing the techniques.

So I have several questions for you. Is it possible that earlier in the experience there was a learning curve associated with doing these repairs that resolved after learning to recognize these events?

Dr Yves d'Udekem (Parkville, Victoria, Australia). We had a lot of discussion mainly between Christian Brizard and myself about what we would do with these complications and we are divided. He tends to believe that we should get away from this technique for bicuspid valve. I tend to still do them for bicuspid aortic valve.

I think that we have in our practice operations that carry dangers, and it's not because there are complications that we should avoid them. It is important for us to realize that there is a risk of

death after an operation; therefore, if you're not comfortable to do them, then you should avoid them. If you are comfortable to do them, you should exercise caution so that these complications do not arise. So I leave it to individual surgeons to decide what to do.

Dr Guleserian. I agree with that. My second question is, again, since you've recognized these events, what specific things have you changed in terms of the technique? Please comment about the glutaraldehyde fixation of the pericardial patches. Has there been any change in that technique in this time period?

Dr d'Udekem. Regarding the techniques, I think that if you have a bicuspid valve, you should make sure that the coaptation of the 3 cusps is central and not eccentric or close to the wall—that's what precipitates the prolapse of the free edge of the leaflet toward the sinus.

Regarding the level of preparation of the pericardium, we are gentler now than in the past. We moved from 6 to 8 minutes preparation with glutaraldehyde to 2 baths of 2 minutes in a flat fashion, in a special press that we have for the pericardium. And then we do full rinsing. I believe it is very important is to have a rinsing with magnesium chloride in the final solution because that detoxifies the glutaraldehyde. It is apparently important.

Dr Guleserian. A lot of other groups have decreased the amount of time of fixation from 10 to somewhere around 5 to 6 and added further modifications.

Not surprisingly in the infant patient group those patients tended to have a shorter durability of their repairs. My last question is: Do you have any insight on how to provide this particular subgroup with a more durable repair over time, particularly if they are undergoing tricuspidization?

Dr d'Udekem. I'm glad you asked this question. We've reviewed specifically our experience with children aged <1 year and we've been able to compare our experience with surgery versus balloon dilatation. In the present work we excluded those who had balloon commissurotomy. But when we looked at the aortic valve surgery that was done in neonates—I think we had a group of about 130 patients with close to 80 of those patients younger than age 1 year—the result was absolutely stunningly in favor of surgery. The freedom from reoperation was far better in the patients operated on using this technique. The frequent techniques were debulking of the valve and creation of neocommissure for unicuspid valve. We didn't do just simple blade commissurotomy and just stick the blade through the valve, we did some more refined work.

Most interesting is that by the time of 10 years follow-up, 20% of patients who had a balloon valvuloplasty only were free of reintervention and of residual stenosis or regurgitation, whereas 40% of those who had surgery were still free of any reintervention and any aortic valve disease. That's a manuscript that's coming up.

Dr Gerhard Ziemer (Chicago, Ill). You showed a picture of your Thoratec patient. This was a pretty tall patient and you had to resuscitate him early after surgery. Was this a case of valvular insufficiency in a Marfan patient? Would you do this type of plastic in a Marfan patient?

Dr d'Udekem. The only surgery that we perform today in Marfan patients is aortic root valve-sparing procedure. During the past 5 years, at least, we have been able to repair all of them with the David procedure. The patient you saw in that picture had a stenotic bicuspid aortic valve with quite thick myocardium.

Dr Ziemer. And a bicuspid Marfan's aortic valve, would you reconstruct it?

Dr d'Udekem. I would tend to repair all of them, yes.

Dr Khanh Nguyen (New York, NY). In the group that developed ischemia, I noticed that 1 sinus tends to be small. We encountered a similar situation in the operating room and the diagnosis was made by echo. The extended cusp seemed to close off the sinus. The maneuver that we tried was to enlarge the sinus and the ischemia went away. If you see a patient with this particular finding, would you try to do something like that to restore flow?

Dr d'Udekem. We didn't think about enlarging the sinus. As all of you know, there are a few articles about cusp extension technique, but this issue was not yet described. I think it's important that it's written that this problem can happen so that surgeons can do either what you've done, or what we've done, and prevent it.

Dr Nguyen. The neonatal group that had the complete 3-leaflet extension—how many of them in your series?

Dr d'Udekem. The complete 3-leaflet extension was done in 35 patients.

Dr Nguyen. And did you find that technically it's harder to do because the valves tend to be thinner and the roots are very small? Any tips on the technique to extend those valves in neonatal patients?

Dr d'Udekem. In neonates younger than 1 year, we found out that generally speaking the disease is predominantly stenotic and we have to—to have a durable repair—increase the effective orifice area. We've tried to repair stenotic bicuspid valve at age 1, 2, and 3 years by leaving them bicuspid and that usually fails. So if we have a bicuspid valve in a child of that age, we make it tricuspid. If we have a neonate with a unicuspid valve, then we tend to put new commissures with 2 triangular patches and we make the valve bicuspid. It's difficult to change a unicuspid valve into a tricuspid valve in a neonate, but it is possible. My colleague Igor did that recently. It's very small. We found it difficult. So we just make it bicuspid.

Dr Giovanni Stellin (Padova, Italy). I would like to congratulate you and Christian Brizard for these excellent results. A 60% freedom from reoperation is an excellent result.

One or 2 patients needed reoperation during the same hospitalization. I wonder whether your repair was successful in all patients, or if in some instance it wasn't judged successful in the operating room and you had to carry on with the valve replacement?

Dr d'Udekem. What happens is that we look at the valve and we make the decision between Ross procedure and valve repair in the aorta. And that's what we tell patients. So far we have not found that echo allows us to predict in advance whether or not we can do a repair.

The idea now is that if we have a 4- or 5-year old, we can almost always repair the valve, and that's the beauty of the cusp extensions. It has to be really extremely thick, it has to be a block of fibrosis with no mobility on the hinge point of the leaflets for you not to be able to repair.

If the valve is extremely dysplastic in a 14-, 15-, or 16-year old, our threshold now is lower just to do a Ross procedure, because it's the time of the patient's life where you want them to be free for 10 or 20 years without any problems. And we don't want to operate at age 16 years and have them back during the middle of their early university years for a second operation.

Dr Stellin. Was any attempt to repair a valve turned into a valve replacement?

Dr d'Udekem. I cannot remember any second run when we did a Ross procedure and so we did repair in all the patients. There was only 1 patient in whom we did a Ross procedure during the same hospital stay. We have some second runs to readjust the valve a little bit at times, but the end result once we started to do a repair was a repair.

Dr Emile Bacha (*New York, NY*). You're talking about 2 problems with your cusp extensions: first is the acute coronary ischemia problem, which I believe a lot of people know about; and second is the worse long-term outcomes. However, you have an inherent selection bias here because usually if you're doing a cusp extension, by definition the anatomy is going to be worse. I don't think that's what you're saying. You're not saying that we shouldn't do cusp extension.

What are you proposing for the very bad valves? What do you suggest at this point in time? Are you suggesting new techniques?

Dr d'Udekem. I think cusp extension technique is a good technique. I think it's worthwhile to repair aortic valves using this technique. It has the advantage of postponing reintervention for a fairly long time. And I think that in congenital disease we will see results similar to those that were published from Saudi Arabia for rheumatic aortic valve disease—the longevity of the repair will be between 5 and 15 years. I believe that by the end of 15 years all of the patients will go back for reoperation.

But I believe that it's a benefit to wait so that a patient can grow to adult size. You can typically never do a Ross procedure with an inclusion technique in these young children who have stenotic valve. If you can wait until they reach adult size to have a Ross procedure, I think you can do a good inclusion technique. My belief is that proceeding this way is going to provide the best future for these patients with very bad disease.

Dr Bacha. On the other hand, the best subset of patients on whom to do a Ross procedure is children with aortic stenosis.

Dr d'Udekem. True.