Valve sparing-root replacement with the reimplantation technique to increase the durability of bicuspid aortic valve repair

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Objectives: To assess root replacement and annular stabilization in bicuspid aortic valve repair, we compared results of reimplantation technique versus subcommissural annuloplasty or no annuloplasty.

Methods: Between 1995 and 2010, 161 consecutive patients underwent bicuspid aortic valve repair. Patients undergoing subcommissural annuloplasty or no annuloplasty (group 1, n = 87) had larger root dimensions and less aortic insufficiency than did patients undergoing reimplantation technique (group 2, n = 74). We matched groups 1 to 1 on basis of those criteria. After matching (n = 106, n = 53 per group), root dimensions (41.5 ± 5 vs 40 ± 4 mm; $P = .2$) and degree of insufficiency (2.6 ± 1.2 vs 2.7 ± 1 ; $P = .6$) were similar between groups.

Results: Techniques of cusp repair were similar between groups. Group 2 had smaller preoperative left ventricular size ($P = .02$), fewer concomitant procedures ($P = .02$), and shorter follow-up (41 ± 30 vs 63 ± 40 months; $P = .003$). There were no in-hospital deaths. At discharge, residual aortic insufficiency was similar between groups, but peak gradient greater than 25 mm Hg was more frequent in group 1 (13% vs 30%; $P = .04$). At 6 years, overall survival was $98\% \pm 3\%$ in both groups. Freedoms from reoperation and aortic insufficiency greater than 2+ were significantly better in group 2 (100% vs $90\% \pm 8\%$; $P = .03$; 100% vs $77\% \pm 14\%$; $P = .002$).

Conclusions: In bicuspid aortic valve repair, root replacement with the reimplantation technique stabilizes the ventriculoaortic junction, improves valve mobility (low gradient), and is associated with improved outcomes. (J Thorac Cardiovasc Surg 2011;142:1430-8)

Bicuspid aortic valve (BAV) is the most common congenital cardiac anomaly in the adult population.¹ Although BAV disease can occasionally be associated with normal lifelong valve function, its presence is associated with a risk of early degeneration leading to aortic insufficiency (AI), stenosis, or aneurysm starting in the third decade of life.² Flow disturbances and intrinsic abnormalities of aortic valve and aortic wall tissues are implicated in the degenerative process.³

In the setting of BAV insufficiency, valve repair has been performed during the last 2 decades with the goal of avoiding prosthetic valve-related complications in this young population. BAV repair is considered to be a valid alternative to replacement, with an 8- to 10-year reoperation rate ranging from 15% to 20%.⁴⁻⁶ The main reason for reoperation is recurrence of AI, which occurs in more

than 90% of patients requiring reoperation.^{5,6} Other than the obvious mechanisms of failure, such as leaflet suture dehiscence, the causes of recurrent AI are rarely reported. In our own series, we have observed technical complications such as suture dehiscence but we have also observed late failures from recurrent cusp prolapse, which can occur as a result of changes in the size and morphology of the aortic root and the functional aortic annulus.⁵ In this context, the nature of annuloplasty at the time of the initial repair can have important prognostic implications for repair durability. The functional aortic annulus, consisting of the ventriculoaortic junction (VAJ) and sinotubular junction (STJ), is best stabilized by performing a valve-sparing root replacement with the reimplantation technique. In the setting of a nondilated aortic root, however, the indications for this more invasive procedure in BAV repair remain controversial. In this study, we compared the results of BAV repair with the reimplantation technique with those of BAV repair with subcommissural annuloplasty or no annuloplasty.

MATERIALS AND METHODS

This study was approved by the ethics review board of the hospital. Written informed consent was waived for this study.

Group Selection and Matching

Between December 1995 and June 2010, a total of 161 consecutive patients with BAV underwent nonemergency valve preservation and repair for

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Abbreviations and Acronyms

AI	= aortic insufficiency
BAV	= bicuspid aortic valve
IQR	= interquartile range
STJ	= sinotubular junction
VAJ	= ventriculoaortic junction

AI or aortic aneurysm. Interventions on the aortic annulus (the VAJ) in this population included no annuloplasty, subcommissural annuloplasty with or without supracoronary ascending aorta replacement, valve-sparing root replacement with the reimplantation technique, or use of the remodeling technique (no VAJ annuloplasty). These patients were divided into 2 groups on the basis of the type of VAJ annuloplasty (Figure 1). Patients who underwent repair with no annuloplasty, subcommissural annuloplasty, or the valve-sparing procedure with the remodeling technique ($n = 87$) were compared with patients who underwent repair with the valve-sparing procedure with the reimplantation technique ($n = 74$). Comparison of preoperative characteristics revealed that patients undergoing the valve-sparing procedure with the reimplantation technique had larger root diameter (sinus of Valsalva, 44 ± 8 mm vs 38 ± 5 mm; $P < .001$), less AI (mean AI, 28 ± 1 vs 25 ± 1 ; $P = .04$), and later operation (mean follow-up, 71 ± 43 months vs 40 ± 33 months; $P < .001$). Because root diameter and AI clearly influenced the selection of operative technique, we matched patients 1:1 on the basis of these 2 variables in a hierarchic fashion (maximum aortic root diameter followed by preoperative AI). Maximum aortic root diameter and AI, as assessed by preoperative echocardiography, were categorized as follows: diameter less than 35 mm, 36 to 40 mm, 41 to 45 mm, 46 to 50 mm, or greater than 51 mm, and AI grade 0 to 2+ or at least 3+. This process resulted in 53 matched pairs (total $n = 106$), and their preoperative and intraoperative characteristics are listed in Table 1.

Surgical Techniques

Techniques of aortic valve repair and the surgical approach to BAV repair have been previously described.⁵ The subcommissural annuloplasty was generally performed at each commissure of the valve with polytetrafluoroethylene-reinforced braided sutures. The U-shaped suture was passed horizontally through the aortic wall from one side of the commissure to the other. The annuloplasty was performed at the half of interleaflet triangle height or lower to obtain greater plication. Supracoronary ascending aorta replacement was performed with a straight Dacron polyester fabric tube sized on the STJ that corresponded to good cusp coaptation. Root remodeling was performed with a straight Dacron polyester fabric tube similarly sized. In patients presenting with dilatation of a single sinus only (generally the noncoronary sinus), partial root remodeling was performed. During the study period, root remodeling has been progressively less used in favor of the reimplantation technique. Subcommissural annuloplasty was frequently associated with supracoronary ascending aorta replacement and root remodeling to increase cusp coaptation and stabilize the VAJ.

Of importance for this study is that during the study period we expanded the indications for root replacement with the reimplantation technique in the setting of BAV repair. This evolution toward a lower threshold of aortic size to perform reimplantation was motivated in part by the change in the recent guidelines as well as from our own experience. For the reimplantation technique, root dissection is performed deep to the level of cusp insertion. The prosthesis is tied down proximally with 12 polytetrafluoroethylene-reinforced braided sutures passed under the cusps all around the valve circumference (Figure 1, B).⁷ Since 2002, the Gelweave Valsalva graft (Vascutek Ltd, a Terumo Company, Renfrewshire, Scotland) has progressively replaced the Dacron polyester fabric tube graft in the reimplantation

technique. Initially, the graft was sized on the basis of the STJ size that corresponded to good cusp coaptation, a value to which we added 4 to 5 mm to obtain prosthesis diameter. During the past 2 years, we have changed our method, and we now actually measure the height of the commissure between the noncoronary and the left coronary sinuses, which corresponds to the graft diameter.⁸

The repair techniques to manage conjoint cusp raphe consisted of shaving (eg, in case of rudimentary raphe), resection, and direct closure, or of resection and repair with a pericardial patch. Cusp prolapse was treated by free margin central plication or by free margin resuspension with a running suture of polytetrafluoroethylene.⁹ Cusp perforation was repaired with a pericardial patch. In the absence of root replacement, cusp repair was generally performed first, followed by subcommissural annuloplasty and then by the supracoronary ascending aorta replacement when necessary. When root replacement was planned, raphe or cusp perforation was repaired first, and then the root replacement was performed. After root replacement, cusp coaptation was reevaluated, and any residual cusp prolapse was corrected.

Echocardiographic Assessment

After repair, transesophageal echocardiography was performed in all patients to assess the degree of residual AI, orientation of the regurgitant jet (if present), and the coaptation length and height. Coaptation length of at least 5 mm at the midportion of the free margin or a coaptation height above the aortic valve annulus were prerequisites for a successful repair, and the presence of an eccentric residual AI jet was an indication for reexploration of the aortic valve.¹⁰

Follow-up

Clinical follow-up was conducted through outpatient visits or as telephone follow-up by a research nurse. Information on survival status and valve-related complications, including thromboembolism, hemorrhage, endocarditis, reoperation, and cardiovascular symptoms, was obtained as defined in published guidelines. Transthoracic echocardiography was performed in all patients before discharge and at regular intervals during follow-up. The closing interval for the study was between September 2010 and December 2010. Clinical follow-up (median, 52 months; interquartile range [IQR], 18–91 months) and echocardiographic follow-up (median, 46 months; IQR, 17–81 months) were complete in 99% and 98% of cases, respectively.

Statistical Analyses

Continuous data are presented as mean $\pm$ SD, or as median with IQR, for nonparametric data. Failure time data on survival, reoperation, and recurrent AI are presented with Kaplan-Meier survival curves. Patients undergoing aortic valve rerepair were not reentered into the database for calculation of reoperation-free survival. The date of the first diagnosis of recurrent AI greater than grade 2+ was recorded for time-to-event calculation. Comparisons between groups for failure time data were performed with the log-rank test. Statistical analyses were performed with the SAS version 9.1 statistical software package (SAS Institute, Inc, Cary, NC). Graphs were constructed with GraphPad Prism 5.0 (GraphPad Software, Inc, La Jolla, Calif).

RESULTS

Preoperative and Intraoperative Data

Table 1 compares the preoperative and intraoperative data between groups 1 and 2. Except for slightly larger left ventricular dimensions in group 1, preoperative variables were similar in the matched groups. Notably, the specific variables used for matching, severity of AI and root diameter (sinus of Valsalva), showed similar distribution and mean value, respectively, in matched groups. The others

Group 1 (unmatched, n= 87)	Group 2 (unmatched, n= 74)
Definition: BAV repair without VAJ annuloplasty or with subcommissural annuloplasty (SCA)	Definition: BAV repair with circumferential VAJ annuloplasty
<ul style="list-style-type: none"> - No annuloplasty (cusp repair only) 5 (6%) - SCA 48 (55%) - Ascending aorta replacement 4 (5%) - Ascending aorta replacement + SCA 13 (15%) - Aortic root remodeling¹ 7 (8%) - Aortic root remodeling¹ + SCA 10 (11%) 	<ul style="list-style-type: none"> - Valve sparing reimplantation technique ² 74 (100%)

FIGURE 1. Definition of the study groups. BAV, Bicuspid aortic valve; VAJ, ventriculoaortic junction; SCA, subcommissural annuloplasty. ¹Root remodeling was performed with replacement of a single sinus of Valsalva (partial remodeling) in 14 patients and with replacement of both sinuses (complete remodeling) in 3 patients. ²Reimplantation was performed with Dacron polyester tube graft in 23 patients (31%) and with a Gelweave Valsalva graft (Vascutek Ltd, a Terumo Company, Renfrewshire, Scotland) in 51 patients (69%). A, Illustration of subcommissural annuloplasty suture (black arrow). B, Illustration of proximal circumferential suture line (white arrows) in reimplantation technique.

dimensions of the proximal aorta (VAJ, STJ, and ascending aorta) were also similar between groups.

Aortic cusp repair was performed frequently and in similar proportions in both groups (98% vs 93%; $P = .36$), and the different techniques used for cusp repair were similarly used in both groups. The need for aortic valve reexploration was also similar between groups. Finally, a higher rate of concomitant procedures was observed in group 1 (21% vs 4%; $P = .018$), and a longer procedure time was observed in group 2 ($P < .001$).

Early Outcomes

In the entire cohort, there were no in-hospital deaths. Aortic valve repair-related complications are listed in Table 2. There were no significant differences in term of reoperation for bleeding, permanent pacemaker implantation, and stroke between groups. Early aortic valve reoperation was necessary for 4 patients from group 1 (7.5%; days 6, 7, 10, and 12) and none from group 2. These cases occurred early in our experience, and the causes of repair failure were largely technical, including cusp perforation, suture dehiscence, cusp prolapse, and fistula between the aortic root and the right ventricle. Of those patients undergoing aortic valve reoperation, 3 underwent aortic valve re-repair and one underwent a Ross procedure. On discharge echocardiography, residual AI was similar in both groups. Group

1 presented with significantly higher transvalvular peak gradient than did group 2.

Clinical Follow-up

Clinical follow-up was complete in 100% and 98% of cases in groups 1 and 2, respectively. Patients from group 1 had longer clinical follow-up (median, 50 months; IQR, 26–96 months) than did those from group 2 (median, 34 months; IQR, 13–63 months). One patient died in each group; the cause of death was unknown in the patient from group 1, whereas the cause in the patient from group 2 was congestive heart failure after reoperation for coronary surgery with a normally functioning aortic valve. At 6 years, overall survival was $98\% \pm 3\%$ in both groups (Figure 2, A). Late reoperations were necessary in 3 patients from group 1 (2 recurrent AI, 1 endocarditis) after 23, 76, and 120 months. At 6 years, freedoms from aortic valve reoperation, including early reoperation, were $90\% \pm 8\%$ in group 1 and 100% in group 2 ($P = .025$; Figure 2, B).

Two patients in group 1 had endocarditis; 1 of these underwent aortic valve reoperation (as described in the next paragraph), and 1 of these was treated medically. At last follow-up, New York Heart Association functional class I, II, or III symptoms were present in 83%, 17%, and 0%, respectively, of patients in group 1 and in 86%, 12%, 2%, respectively, of patients in group 2 ($P = .3$).

TABLE 1. Preoperative patient characteristics and intraoperative data within matched groups

	Group 1 (n = 53)	Group 2 (n = 53)	P value
Age (y, mean ± SD)	47 ± 11	44 ± 11	.13
Male (no.)	49 (93%)	50 (94%)	>.999
New York Heart Association functional class (no.)			.12
≤1	21 (40%)	30 (57%)	
>1	32 (60%)	23 (43%)	
Previous cardiac surgery (no.)	0 (0%)	1 (2%)	>.999
Aortic insufficiency grade (no.)			.58
≤1	8 (15%)	13 (25%)	
2	12 (23%)	7 (13%)	
3	22 (42%)	20 (38%)	
4	11 (21%)	13 (25%)	
LV end-systolic diameter (mm, mean ± SD)	41 ± 10	38 ± 7	.02
LV end-diastolic diameter (mm, mean ± SD)	61 ± 9	58 ± 7	.03
LV ejection fraction (no.)			.36
>50%	45 (85%)	49 (92%)	
<50%	8 (15%)	4 (8%)	
Aortic diameter (mm, mean ± SD)			
Ventriculoaortic junction	27 ± 3	28 ± 3	.18
Sinuses of Valsalva	40 ± 4	41.5 ± 5	.18
Sinotubular junction	36 ± 5	37 ± 5	.34
Ascending aorta	44 ± 8	45 ± 7	.35
Aortic cusp repair (no.)			
All	52 (98%)	49 (93%)	.36
Raphe shaving	11 (21%)	12 (23%)	>.999
Raphe resection and primary closure	23 (43%)	20 (38%)	.69
Raphe resection and patch repair	9 (17%)	6 (11%)	.40
Cusp prolapse repair	42 (79%)	41 (77%)	>.999
Patch repair for cusp perforation	3 (6%)	3 (6%)	>.999
Any patch repair	12 (23%)	9 (17%)	.47
Functional aortic annuloplasty (no.)			
SCA	24 (45%)	—	
Ascending aorta replacement	3 (6%)	—	
Ascending aorta replacement plus SCA	12 (23%)	—	
Valve-sparing remodeling*	4 (7%)	—	
Valve-sparing remodeling* plus SCA	10 (19%)	—	
Valve-sparing reimplantation	—	53 (100%)	
Intraoperative aortic valve reexploration (no.)	4 (8%)	1 (2%)	.36
Concomitant procedures† (no.)	11 (21%)	2 (4%)	.02
Cardiopulmonary bypass time (min, mean ± SD)	94 ± 31	131 ± 24	<.001
Aortic crossclamp time (min, mean ± SD)	73 ± 24	113 ± 22	<.001

LV, Left ventricular; SCA, subcommissural annuloplasty. *Replacement of a single sinus of Valsalva only (partial remodeling, n = 13) or replacement of both sinuses (complete remodeling, n = 1). †Concomitant procedures were mitral valve repair (n = 4), coronary artery bypass grafting (n = 5), and aortic arch replacement (n = 4).

TABLE 2. Early postoperative outcomes within matched groups

	Group 1 (n = 53)	Group 2 (n = 53)	P value
Postoperative outcomes			
Mortality	0	0	—
Reoperation for bleeding	6 (11%)	7 (13%)	>.999
Aortic valve reoperation	4 (7.5%)	0	.13
Permanent pacemaker insertion	2 (4%)	4 (8%)	.67
Stroke or transient ischemic attack	2 (4%)	2 (4%)	>.999
Discharge echocardiography*			
Aortic insufficiency grade			
0	26 (53%)	32 (62%)	
1	20 (41%)	19 (36%)	.46
2	3 (6%)	1 (2%)	
Peak gradient			
≤20 mm Hg	25 (51%)	42 (81%)	
21–30 mm Hg	14 (29%)	7 (13%)	.006
>30 mm Hg	10 (20%)	3 (6%)	

All data represent numbers and percentages of patients. *Early reoperation excluded.

Echocardiographic Follow-up

Echocardiographic follow-up was complete for 98% of patients in both groups. Patients from group 1 had longer echocardiographic follow-up (median, 48 months; IQR, 21–84 months) than did those from group 2 (median, 32 months; IQR, 11–63 months). At 6 years, freedoms from AI greater than 2+ were 77% ± 14% in group 1 and 100% in group 2 ($P = .002$). Freedoms from AI greater than 1+ were 64% ± 15% in group 1 and 95% ± 5% in group 2 ($P = .0006$; Figure 2, C and D).

Mean transvalvular gradient greater than 40 mm Hg was observed in 2 patients from group 1 and in 1 patient from group 2 after 97, 143, and 83 months, respectively. All 3 patients were free of symptoms at last follow-up.

Mechanisms of Repair Failure in Late Reoperations (Unmatched)

In the entire cohort (n = 161), a total of 9 patients underwent late aortic valve reoperation after a mean follow-up time of 73 ± 30 months (Table 3). All those patients were from (unmatched) group 1, and the reasons for reoperation were recurrent AI (n = 7), endocarditis (n = 1), and stenosis (n = 1). In the patients with AI, echocardiographic analysis and intraoperative findings revealed that cusp prolapse associated with VAJ dilatation was the principal mechanisms of recurrent AI (Figure 3). With complete echocardiography available in 7 patients undergoing late reoperation, comparison between early postoperative and preredo VAJ diameter values showed a mean increase of 4.4 ± 0.5 mm ($P < .001$) during a mean interval of 5 ± 3 years. The details of reoperations are listed in Table 3.

DISCUSSION

Although valve repair for BAV insufficiency is considered an acceptable alternative to replacement; repair failure,

FIGURE 2. Kaplan-Meier actuarial survival curves comparing group 1 and group 2. A, Overall survival ($P = .9$). B, Freedom from aortic valve reoperation ($P = .025$). C, Freedom from recurrent aortic insufficiency greater than 2+ ($P = .002$). D, Freedom from recurrent aortic insufficiency greater than 1+ ($P = .0006$).

largely caused by recurrent AI, remains the principal concern that limits application of this technique. In this study, we demonstrated that valve-sparing root replacement with the reimplantation technique can significantly increase durability of BAV repair without additional morbidity relative to less aggressive annuloplasty. The lower immediate post-operative transvalvular gradients suggest increased valve mobility after reimplantation in comparison with the other techniques. Furthermore, echocardiographic review of

repair failures confirms that the VAJ can dilate years after subcommissural annuloplasty.

Despite critiques on the nonphysiologic cusp motion and potential cusp damage caused by the elimination of the Valsalva sinuses, the reimplantation technique is associated with excellent valve durability and long-term outcomes.^{11,12} Moreover, the type of graft (eg, Valsalva graft) and the techniques used actually can recreate the Valsalva sinuses in shape and improve cusp motion.¹²⁻¹⁴

TABLE 3. Details of late bicuspid aortic valve reoperations (unmatched)

Bicuspid AV repair	Redo delay (y)	Functional AA plasty	Raphe repair	Other cusp repair technique	VAJ postop*	VAJ redo*	VAJ difference†	Failure mechanism	Type of AV reoperation
1996	8	AA replacement	Primary closure	Decalcification	NA	23	NA	AS	Bioprosthesis
2000	7	SCA	Shaving	FMP, FMR	NA	23	NA	AI and AS	Bioprosthesis
2001	2	SCA	Patch	—	20	24	4	AI, prolapse	Ross
2001	10	SCA	Shaving	FMR	27	32	5	AI, prolapse	Rerepair reimplantation
2002	6	SCA	Primary closure	FMR	21	25	4	AI, prolapse	Ross
2002	6.5	Remodeling, SCA	—	FMP	19	23	4	AI, endocarditis	Rerepair
2002	6.5	SCA	Primary closure	FMR	24	29	5	AI, prolapse	Rerepair reimplantation
2003	6.5	SCA	Patch	—	24	29	5	AI, prolapse	Bioprosthesis
2007	2	SCA	—	FMP, FMR, patch on perforation	28	32	4	AI, prolapse	Bioprosthesis

AV, Aortic valve; AA, aortic annulus; VAJ, ventriculoaortic junction; NA, not available; AS, aortic stenosis; SCA, subcommissural annuloplasty; AI, aortic insufficiency; FMP, free margin plication; FMR, free margin resuspension (with running suture of polytetrafluoroethylene 7/0). *Echocardiographic measures of the ventriculoaortic junction diameter (in millimeters) on long-axis view, measures were taken on postrepair and prereditransesophageal echocardiography. †Difference between postoperative and follow-up measures of ventriculoaortic junction.

FIGURE 3. Illustration of ventriculoaortic junction redilatation in a 30-year-old man undergoing bicuspid aortic valve repair with subcommissural annuloplasty, raphe resection and direct closure, and resuspension of both cusps with polytetrafluoroethylene. Echocardiographic long-axis views show the ventriculoaortic junction diameter (arrows) before bicuspid aortic valve repair (A, 29 mm), after bicuspid aortic valve repair (B, 24 mm), and 6.5 years later, before bicuspid aortic valve reoperation for recurrent aortic insufficiency (C, 29 mm).

In this study, we have demonstrated an advantage of the reimplantation technique in BAV repair even for patients with mild to moderate root dilatation. The stability through time of the VAJ annuloplasty performed in the reimplantation technique probably explains the differences observed between the 2 groups. VAJ dilatation is common in BAV, and a proportional relationship has been shown with the degree of regurgitation.^{6,15} We observed recurrent dilatation of VAJ after subcommissural annuloplasty in patients needing reoperation. Similarly, Aicher and associates have found, among others factors, both the preoperative VAJ diameter and subcommissural annuloplasty independent predictors of BAV repair failure.

The better durability observed in the reimplantation technique may not be only due to the VAJ annuloplasty offered by this technique. Effectively, we observed after the reimplantation technique lower transvalvular gradient in comparison to group 1. This observation, resulting from improved cusps mobility, is related to the functional aortic annulus (VAJ plus STJ) and valve reshaping during reimplantation. During the past 2 years, we fashioned the VAJ annuloplasty during the reimplantation procedure in such a way as to reduce the base of implantation of the conjoint cusp. This technique makes the valve more symmetric and decreases cusp tension, which is of particular interest after raphe resection. As such, decreased cusp tension allows in certain cases to perform direct closure instead of cusp extension with pericardial patch, which is a predictor of repair failure.

In BAV repairs, Aicher and colleagues⁶ have also reported a better durability with valve-sparing surgery, but with the remodeling technique. This suggests that both valve-sparing procedures exert several beneficial effects on the repair. One is a better stabilization of the functional aortic annulus, and another is the potential to improve

the valve configuration during surgery. We have concerns, however, about the absence of VAJ annuloplasty in the remodeling technique. Effectively, it may be responsible for late AI recurrence as reported by some, especially in patients with VAJ dilatation.^{12,16} For this reason, those who routinely use the remodeling technique actually recommend the addition of a VAJ annuloplasty.^{6,17}

During the study period, we have increased our indications to perform root replacement with the valve reimplantation technique. Our motives were principally related to pathoanatomic changes present in BAV disease. In addition to the dilatation of the root and ascending aorta, tissues generally present with increased fragility, and locally the wall of the Valsalva sinuses may be particularly thin. This last feature is best observed at the bases of the right and the non-coronary sinuses, where the aortic wall appears translucent with sometimes a localized aneurysmal appearance. Thinning of the sinuses does not always seem proportional to the severity of root dilatation, and it may be associated with distal migration of the coronary ostia. The aortic wall thinning and fragility should be considered as the macroscopic expression of histologic and molecular abnormalities observed in the aortic media of patients with BAV.^{3,18} It has not been reported how thinning specifically affects patient outcome, but in our experience, it may be a source of both intraoperative complications (eg, wall perforation with subcommissural annuloplasty stitches) and late complications (eg, progressive dilatation of the VAJ and recurrent AI).

In patients with BAV, guidelines recommend aortic replacement for aortic diameter greater than 50 mm in the absence of valve dysfunction and 45 mm in the setting of concomitant valvular surgery.¹⁹ However, regarding literature data, the thresholds for aortic replacement remains controversial.²⁰⁻²⁴ Data from the international registry of acute aortic dissection show that approximately 20% of type A

dissections occur with aortic diameter smaller than 45 mm²⁰; considering BAV only, however, this prevalence seems to drop below 5%.²⁴ In a large retrospective review of outcomes after BAV surgery, Svensson and associates²² have reported a very low risk of aortic events after midterm follow-up (mean 6 years) in patient with aortic diameter smaller than 45 mm at surgery. In similar patients, Borger and colleagues²¹ have reported a relatively high rate of 20% of ascending aorta complications after 15 years of follow-up. In our surgical practice, we have expanded the indication for root replacement in BAV with the objective of improving immediate and long-term results of BAV repair, and not with the intent to prevent the aortic complications related to BAV aortopathy. Consequently, these indications are not applied for BAV replacement. Moreover, we were able to maintain low mortality and morbidity with this aggressive root replacement approach. In comparison with patients from group 1, these patients showed a higher rate of permanent pacemaker implantation after the reimplantation technique (8% vs 4%; $P = .67$); however, the 4.8% rate of pacemaker implantation in our global experience with the reimplantation technique is probably a more representative number.

In patients presenting with recurrent AI, the choice of re-repair versus replacement is not simply a technical surgical decision but also takes into account patient age, comorbidities, and, most importantly, the patient's wishes regarding another attempt at repair. Because our understanding of the mechanism of failure in these patients has improved, we can more confidently offer a re-repair with the reimplantation technique to selected young patients. As a result, among the most recent 3 patients needing reoperations for recurrent AI, re-repair with the reimplantation technique was performed in 2 cases (Table 3). After 1 and 2 years after reoperation, these 2 patients have remained free of symptoms, with no AI to mild AI.

Study Limitations

One limitation of this study is related to its nonrandomized design from a center where the surgical approach to BAV has evolved with time to favor the reimplantation technique. Thus the reimplantation technique was performed more frequently in recent years, resulting in a shorter mean duration of follow-up for these patients. Similarly, because patients with reimplantation underwent operations more recently, we can assume that they have benefited from our increased experience with BAV repair relative to the other group.

CONCLUSIONS

In conclusion, root replacement with the reimplantation technique stabilizes the functional aortic annulus (VAJ + STJ), improves valve mobility (low gradient), and is associated with improved outcomes in patients undergoing BAV

repair. Aggressive root replacement with the reimplantation technique, even in patients with mild to moderate root dilatation (<45 mm), can improve outcomes after BAV repair.

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Discussion

Dr Thomas J. Gleason (Pittsburgh, Pa). I have no disclosures. First, I congratulate de Kerchove and colleagues for an outstanding presentation, and I thank them for supplying me with the manuscript early, as I enjoyed reading it very much.

I strongly agree with the concept that BAV repair in combination with a reimplantation technique offers the best bicuspid valve repair. In that context, I have followed Dr El Khoury's work for the last many years with great interest, and this study is yet another example of his fine skill as a surgeon and his careful review of his own work. These operations can be quite intellectually challenging with respect to knowing what to do with the cusps and the annulus and what not to do in a given case, and I commend your group in doing so with no operative mortality and very low morbidity. Beyond these acknowledgements, I have 4 distinct questions, which perhaps we should address 1 at a time.

Most of the failures were listed as due to cusp prolapse, and the explanation of insufficiency was explained as a process of delayed and progressive dilatation at the VAJ, with a mean increase among the failures of 4.4 mm. If, however, there were simply dilatation of the VAJ, or, to use Sir Magdi Yacoub's term, the "surgical annulus," then it would seem that most patients could undergo rerepair with reimplantation of the valve. Yet only 2 of the 9 affected patients underwent subsequent reimplantation. Were there also concomitant cusp issues at the time of reoperation, and if so, what were they?

Dr de Kerchove. Thank you, Dr Gleason, for your very kind comment and for this first pertinent question. The reoperation after a previous aortic valve repair is a very different situation from that of a first aortic valve repair. First, in reoperation, cusp issues may coexist with VAJ dilatation. For example, in this series, 1 patient had focal cusp calcification and another required primary repair with a pericardial patch. In such situations, simple rerepair is obviously contraindicated. Second, at reoperation, patients may be 7 to 10 years older and thus may be better candidates for bioprosthetic replacement, rather than for valve repair. Third, after a first repair, patients are not always agreeable to undergo a second repair. And finally, in addition to those cusp or patient issues that make rerepair feasible or not, we have to recognize that the understanding of the mechanism of failure and the confidence within the reimplantation technique are relatively recent. Rerepair with reimplantation was only used twice in the most recent reoperative cases. With the encouraging early outcomes that we obtained

with those last reoperations, we certainly will continue to propose reimplantation in cases of repair failure when it is justified.

Dr Gleason. Second, you do not show all of the follow-up echocardiographic data, giving only the rate of 3+ or greater AI at late follow-up. How many patients in the 2 groups had 1 or 2+ AI at follow-up, and was there a recurrent pattern of repair maneuver or maneuvers that had a propensity toward recurrent AI of any degree, be it mild or moderate? I suspect that we could learn a lot from these data as well. What have you learned about what other issues, whether cusp, aortic, or technically related, portend a higher rate of failure beyond simply dilatation of the surgical annulus?

Dr de Kerchove. This study was designed to compare the clinical outcomes of the 2 groups, and we therefore examined only end points representative of severe repair failure, a clinical outcome such as aortic valve reoperation and the recurrence of severe AI. We didn't look at the mechanism of AI in patients with mild to moderate recurrent AI. We built on a Kaplan-Meier curve for moderate or greater recurrent AI, and we observed that the advantage for the reimplantation group was even more statistically significant by using this end point. This result supports our hypothesis regarding the cause of repair failure in patients without circumferential ventriculoaortic annuloplasty; however, we agree that it does not explore the role of other cusp or technical issues in recurrent AI.

We are currently doing echocardiographic studies with this cohort of patients in which root dimensions and cusp function are analyzed with time. The objective is to discover the technical or morphologic factors related to recurrent AI.

Dr Gleason. Third, could you provide us with a bit more detail with respect to your concept of annuloplasty associated with your specific reimplantation technique? My interpretation of your description is that you are placing your primary sutures through the surgical annulus or the VAJ in a manner similar to what Dr David described years ago. I think that this technique is more of an annular support than an annuloplasty, because one does not necessarily change the anatomic annular shape with this technique.

My own view is that what is critical to a durable repair is the concomitant correction of the primary angle of the subcommissural triangle back to a more acute angle, restoring anatomic annular geometry in cases where there is annuloaortic ectasia of any significance. In other words, one must reconfigure the anatomic annulus or the hinge point of the cusps to where they were when the valve was competent earlier in that patient's life. Are you changing the shape of the anatomic annulus in the areas of the subcommissural triangles with your technique, or are you simply supporting the annulus to prevent subsequent dilatation?

Dr de Kerchove. I agree with you in considering that the reimplantation technique provides only a support of the VAJ when only 3 to 6 stitches are used for the proximal suture line. In our technique, however, the proximal suture line is more like a true annuloplasty. Effectively, we kept the original technique and we use 10 to 12 stitches for the proximal suture line. The compression exercised by each stitch induces circumferential remodeling of the VAJ. The decrease in the VAJ diameter is approximately 5 mm. It is possible to adjust the remodeling or annuloplasty effect by adapting the width of the stitches and the strength used to tie them. For example, in type 0 bicuspid valve, where the valve is asymmetric, we place the stitches symmetrically under both cusps

to respect the valve morphology. At the opposite extreme, in a type 1 bicuspid valve, where the valve is generally asymmetric with the conjoint cusp being larger, we place wider stitches under the conjoint cusp than under the opposite cusp to perform a greater annular compression at this level. This annuloplasty associated with symmetric reimplantation of the commissures has 2 advantages in our opinion. One advantage is that you decrease the tension on the conjoint cusp, which will facilitate repair of the raphe and decrease the need for patch augmentation. The second advantage is that you give the valve more symmetry, which seems to improve durability of the repair, as suggested by Dr Schäfers in a recent publication.

Dr Gleason. Finally, I am intrigued by your protocol that aims for a 5-mm coaptation length or depth at the midportion, because, as you know, the coaptation length of a normal aortic valve and a normally functioning BAV is nowhere near 5 mm but much closer to 1 to 2 mm. I suspect that if we aim for a 5-mm coaptation, likening it to goals of mitral valve repair—that is, that more coaptation is better—we will see much more aortic cusp sclerosis with time along the leading edge, such as you may have seen in the 2 patients who had subsequent development of aortic stenosis at years 7 and 8. Could you please explain why you do not aim for a more anatomic correction but rather for this “overcorrection”?

Dr de Kerchove. I agree with you regarding the negative impact of overcorrection on repair durability. The 5-mm cutoff length to which you make reference has been found in an echocardiographic study from our team. In this study, we looked for echocardiographic parameters of tricuspid aortic valve and BAV repair failure. We found that a coaptation length less than 4 mm, the presence of an eccentric regurgitant jet, and a valve coaptation below the level of the annulus were independent predictors of late failure. Currently, we place the greatest importance on the level of coaptation. So if the valve is above the plane of the VAJ and the top of the coaptation reaches the midpoint of the sinuses of Valsalva, I agree with you that you don't need a coaptation length as long as 5 mm. In some cases, when you end up with some degree of valve billowing, meaning that a portion of the body of the cusp is below the plane of the VAJ, we think that a 5-mm coaptation provides greater security for long-term durability, rather than being a sign of prolapse overcorrection.

Dr Gleason. I would argue that the means to eliminate that exact issue would be a proper annuloplasty, and that is really my point, in that in lieu of a proper annuloplasty, one can create a more redundant coaptation depth, but this may in fact impart delayed failure down the road.

Dr de Kerchove. I agree with you that the role of annuloplasty is primal.

Dr Michael P. Siegenthaler (*Bethesda, Md*). Some of your patients had mild to moderate aortic stenosis after these repairs. What is the natural history if you look at those patients long term? Does it stay the same, or do some of them have calcification? What was your observation with these mildly stenotic repaired BAVs?

Dr de Kerchove. For mild or moderate stenosis induced by the repair, most of the gradients remained stable with time, especially when patients were young with no cusp calcification at all at the time of repair. In older patients, or those with calcification at the time of the repair, the risk of observing progressive increase of gradients is real. At this stage of the follow-up, however, valve stenosis represents only 10% of the late failures, and reoperation for stenosis was performed after 8 years, showing that the valve calcification is a relatively slow process.

Dr Tirone E. David (*Toronto, Ontario, Canada*). This article is too important to let go by without a remark. Repair of BAV is much more complex than repair of tricuspid aortic valve, and those present here who do this operation know that. Dr Gleason raised some very important issues about the annuloplasty. The dilatation of the aortic annulus is not symmetric. It is almost entirely on the fibrous skeleton of the outflow tract, and as it dilates, the fibrous skeleton sinks in on the mitral valve. The level of the false commissure is thus much higher than the posterior annulus. How do you compensate for that during reimplantation of the aortic valve? Dr El Khoury, that is a bit unfair to him.

Dr El Khoury. In type 1, I agree that there is a difference in the level. What we do is we try by sparing surgery first to have a really 180° repair. Now, the second issue is, and I agree with you that we should see what to do with the false commissure. Now, if you implant it at the same level, you will have a lack of tissue, because the valve will be like that [hand gesture]. So why we try to put it a little bit like that [hand gesture] to have this coaptation at this level. So we respect it a little bit. But Dr Gleason's point is very well taken. If you close the subcommissural triangle, you do this naturally by making the angle more acute, as opposed to obtuse. In type 1, the formation of the angle is asymmetric; it is like that [hand gesture]. So we try to make it this way [hand gesture]. But the risk is if you put it very low, you will have a valve flapping like that [hand gesture]. So we put it a little bit higher to have the same level of coaptation.

Dr David. He underscores what I said again. It is not a simple repair; reimplantation of BAV is not simple.