Repair of regurgitant bicuspid aortic valves: A systematic approach

Munir Boodhwani, MD, MMSc,^{a,b} Laurent de Kerchove, MD,^a David Glineur, MD,^a Jean Rubay, MD,^a Jean-Louis Vanoverschelde, MD,^a Philippe Noirhomme, MD,^a and Gebrine El Khoury, MD^a

Objective: Patients with bicuspid aortic valves can present with aortic insufficiency caused by cusp disease or the aortic root pathology. We present our 13-year experience with a functional and systematic approach to bicuspid aortic valve repair.

Methods: Between 1995 and 2008, 122 consecutive patients (mean age, 44 ± 11 years) with bicuspid aortic valves underwent non-emergency valve repair for isolated aortic insufficiency (43%), aortic root dilatation (14%), or both (43%). Preoperative echocardiography identified aortic dilatation ($n = 75$), cusp prolapse ($n = 96$), and cusp restriction ($n = 45$) as mechanisms of aortic insufficiency. Raphé repair ($n = 98$) was performed by shaving (21%) or resection with primary closure (60%) or pericardial patch (18%). Functional aortic annuloplasty was performed using subcommissural annuloplasty ($n = 51$), ascending aortic replacement ($n = 17$), or aortic root replacement ($n = 54$) using a reimplantation (76%) or remodeling technique (24%).

Results: There was no operative mortality. Five patients underwent early aortic valve reoperation (3 re-repairs). At discharge, 93% of patients had aortic insufficiency grade 0/1 and 7% of patients had grade 2. Seven additional patients underwent aortic valve reoperation during follow-up (2 re-repairs). Overall survival was $97\% \pm 3\%$ at 8 years. At 5 and 8 years follow-up, freedom from aortic valve reoperation was $94\% \pm 2\%$ and $83\% \pm 5\%$, respectively, and freedom from aortic valve replacement was $96\% \pm 2\%$ and $90\% \pm 5\%$, respectively. Freedom from recurrent aortic insufficiency ($>2+$) was $94\% \pm 3\%$ at 5 years. Freedom from thromboembolism and bleeding was $96\% \pm 2\%$ at 8 years.

Conclusion: A systematic approach to bicuspid aortic valve repair yields good early and midterm results. Repair of bicuspid valves for aortic insufficiency is a feasible and attractive alternative to mechanical valve replacement in young patients. (J Thorac Cardiovasc Surg 2010;140:276-84)

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Bicuspid aortic valves (BAVs) are present in 1% to 2% of the population. Longitudinal studies of patients with this valvular abnormality have demonstrated that they have equivalent survival compared with the general population. However, a large proportion of them require surgical intervention because of disease of the valve or ascending aorta.^{1,2} These patients often present in the third, fourth, or fifth decade with their valvular disease and thus are likely to live for 30 to 50 years after their intervention. This makes

the choice of surgical intervention difficult because of the limitations of currently available valve substitutes. Bioprosthetic valves have a high structural failure rate in young patients (up to 4%/year) requiring multiple re-replacements.³ Mechanical valves have an excellent freedom from reoperation, but risks of thromboembolic events ($\sim 1\% - 2\%$ /year) and anticoagulation-related hemorrhage (2%/year) can carry a significant burden because of the long exposure time.⁴ The Ross operation is ideal for young patients with BAV stenosis because of its durability, excellent patient survival, and low risk of thromboembolic complications.⁵ However, the presence of aortic insufficiency (AI) and aortic root dilatation are important risk factors for pulmonary autograft failure.^{6,7} For all of these reasons, repair of BAVs is an attractive therapeutic option.

Despite numerous attempts at the systematic repair of regurgitant BAVs, there are many questions that remain unanswered. First and most important is whether these valves should be repaired at all. Limited data exist regarding long-term follow-up and valve-related events, and there is little available information that compares valve repair with replacement. Second, what should be the criteria for ascending aortic replacement in these patients who have clearly been demonstrated to have associated aortic abnormalities at the morphologic, histologic, and molecular levels?⁸⁻¹⁰ Third, what is the ideal method for root and annular

From the Department of Cardiovascular and Thoracic Surgery Cliniques Universitaires Saint-Luc,^a Brussels, Belgium; and Division of Cardiac Surgery,^b University of Ottawa Heart Institute, Ottawa, Ontario, Canada.

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Address for reprints: Munir Boodhwani, MD, MMSc, Service de Chirurgie Cardiovasculaire et Thoracique, Cliniques Universitaires Saint-Luc UCL 90, Avenue Hippocrate 10, Brussels B-1200, Belgium (E-mail: mboodhwani@ottawaheart.ca).

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Abbreviations and Acronyms

AI = aortic insufficiency
 AV = aortic valve
 BAV = bicuspid aortic valve

stabilization? Fourth, how should the median raphe be managed? And last, should a pericardial patch be used for cusp augmentation?

This article describes our 13-year experience with BAV repair with a focus on important anatomic features, our surgical approach and techniques, early and midterm clinical and echocardiographic outcomes, a critical analysis of repair failures, and some answers to the questions posed above.

MATERIALS AND METHODS

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

Patient Population

Between December 1995 and September 2008, 122 consecutive patients with BAVs underwent surgery for valve insufficiency or dilatation of the proximal ascending aorta. Although the overall approach to the classification and treatment of AI was guided by our previous study,¹¹ specific features of bicuspid valves were treated as described below. Preoperative characteristics are described in Table 1. Data on surgical techniques were collected prospectively and analyzed retrospectively.

Anatomic Features of Bicuspid Valves

BAV disease affects not only the valve cusps but also the functional aortic annulus, comprising the ventriculoaortic junction, sinuses of Valsalva, sinotubular junction, and tubular ascending aorta.⁹ We have adapted the classification system proposed by Sievers and Schmidtke¹² to aid in the description of cusp anatomy as it relates to valve repair. BAVs may be divided into 2 general types (Figure 1). Type 0 BAVs do not contain a median raphe and have 2 symmetric aortic sinuses, 2 commissures, and a symmetric base of leaflet implantation of the 2 cusps. This configuration is present in a minority of cases. The mechanism of AI in this setting is usually cusp prolapse of 1 or both cusps because of the presence of excess cusp tissue.

Type 1 BAVs, which are significantly more prevalent, have a median raphe on the conjoint cusp and an asymmetric distribution of the aortic sinuses with a large aortic sinus accompanying a large nonconjoint cusp and 2 smaller cusps fused together with a median raphe. The raphe often attaches to the cusp base in the form of a “pseudo-commissure,” which has a height lower than that of the true commissures. The raphe may be restrictive, fibrotic, calcified, or prolapsing. Furthermore, the base of leaflet implantation is typically larger (ie, occupying a greater proportion of valve circumference) and higher on the conjoint cusp compared with the nonconjoint cusp. The mechanisms of AI in type 1 valves can be due to a rigid and restrictive raphe associated with small fused cusps resulting in a triangular coaptation defect. Alternatively, the raphe may be short and nonrestrictive with well-developed cusps and associated prolapse of the conjoint cusp. Although BAVs have classically been described as being type 0 or 1, we have observed that they can be anywhere along a spectrum between type 0 and type 1.

Echocardiographic Evaluation

Preoperative or intraoperative transesophageal echocardiography was routinely performed, focusing on the cusp anatomy (type 0 or 1), mecha-

TABLE 1. Preoperative patient characteristics

Variable	N = 122
Age (y, mean $\pm$ SD)	44 $\pm$ 11
Male gender (%)	113 (92)
NYHA class	
I	38 (31)
II	66 (54)
III	15 (13)
Previous cardiac surgery (%)	5 (4)
LV ejection fraction < 50%	11 (9)
LV end-systolic diameter (mm, mean $\pm$ SD)	40 $\pm$ 8
LV end-diastolic diameter (mm, mean $\pm$ SD)	61 $\pm$ 8
AI grade (%)	
0 or I	17 (14)
II	22 (18)
III or IV	83 (68)
Aortic diameter (mm, mean $\pm$ SD)	54 $\pm$ 8
Indication for surgery	
AI only	52 (43)
Aortic dilatation only	17 (14)
Insufficiency and dilatation	53 (43)

NYHA, New York Heart Association; LV, left ventricular; SD, standard deviation; AI, aortic insufficiency.

nism of AI, type (eccentric vs central), origin (cusp center or along entire cusp free margin) and direction of AI jet, and measurement of components of the aortic annulus (ventriculoaortic junction and sinotubular junction) and the ascending aorta.

Surgical Techniques

Exposure and valve inspection. After median sternotomy and institution of cardiopulmonary bypass and cardioplegia, a transverse aortotomy was performed approximately 1 cm above the sinotubular junction and 4-0 polypropylene sutures were placed at the level of the commissures for exposure. With axial traction (perpendicular to the annular plane) applied on the commissural traction sutures, the aortic valve (AV) was assessed for the mechanisms of AI and the echocardiographic findings were corroborated. Valve assessment specifically focused on cusp anatomy (type 0 vs type 1), the quantity and quality of cusp tissue available, and the presence and location of calcium. The aortic root was inspected for size and the quality of aortic wall tissue.

Cusp repair. The aim of the cusp repair was to restore an adequate surface of coaptation. In type 0 valves, the degree of prolapse was assessed by comparing the prolapsing cusp with the nonprolapsing (reference) cusp. In the case where both cusps were prolapsing, the goal was to restore the height of coaptation to the midpoint of the sinuses of Valsalva. This was performed using free margin plication, free margin resuspension with 7-0 polytetrafluoroethylene suture, or both as previously described.¹³ Thickened, fibrotic areas of the leaflet (typically central aspect of the free margin) were shaved, and localized decalcification was performed if calcium was present.

In type 1 valves, the median raphe was addressed first. If the raphe was relatively mobile and only mildly thickened and fibrosed, it was preserved and shaved. If the raphe was restrictive or calcified, a parsimonious triangular resection of this tissue was performed. Next, the quantity of cusp tissue was assessed by putting the 2 arms of a 6-0 polypropylene suture on the free margin of the conjoint cusp, on either side of the resected raphe (Figure E1, A). At this point, lack of cusp restriction and good valve opening were signs of the presence of adequate cusp tissue. The leaflet edges were reapproximated primarily when adequate cusp tissue was present using running locked or interrupted 6-0 polypropylene sutures (Figure E1, B). In the

FIGURE 1. Variations in BAV cusp anatomy. A, Type 0 valve with symmetric cusps and aortic sinuses and no median raphe. B, Type 1 asymmetric valve with a median raphe, well-developed cusps, excess cusp tissue, and prolapse of the conjoint cusp. C, Type 1 asymmetric valve with a restrictive raphe and central triangular coaptation defect.

absence of adequate tissue, a triangular autologous treated or bovine pericardial patch was used for cusp restoration (Figure E1, C). Next, the free margins of both cusps were compared for the presence of any prolapse, which was corrected using free-margin plication or resuspension with polytetrafluoroethylene (Figure E1, D). Raphe and cusp repair techniques used in this cohort are depicted in Table 2.

Functional Aortic Annulus and Root Management

Intervention on the functional aortic annulus was performed systematically in all patients. In patients with a dilated aortic root (>4.5 cm), the aortic root was replaced preferentially using the reimplantation technique as previously described. In patients with aortic root dimensions less than 4.5 cm, the quality of the aortic wall tissue was carefully assessed. Not infrequently, the aortic wall tissue was fragile and translucent with left ventricular muscle visible through the aortic wall. In other cases, effacement of the sinotubular junction or distal migration of the coronary ostia was observed. In such cases, the aortic root was replaced. Last, in cases where the root was not significantly dilated and the quality of aortic tissue was acceptable, subcommissuroplasty was performed at the 2 commissures as previously described.

Aortic root replacement using the reimplantation technique was the preferred method of root replacement and performed as previously described.¹⁴ In type 0 BAVs with symmetric cusps and sinuses, this symmetry was respected while performing the proximal suture line, prosthesis preparation, and valve reimplantation. In type 1 BAVs with a restrictive raphe and a deficit of cusp tissue on the conjoint cusp, the length of base of leaflet implantation was reduced by making the prosthesis symmetric (even though the natural distribution between the conjoint cusp to nonconjoint cusp was 55% to 45%). This reduction in the base of leaflet implantation provides additional cusp tissue and can help avoid the need for cusp augmentation with pericardium and in some cases may even induce prolapse that then requires correction. A second important variation relates to the height of reimplantation of the pseudo-commissure. Implanting at the level of the cusp base can result in lowering the height of the conjoint cusp, which then requires extension with a pericardial patch, whereas implantation at the level of the 2 normal commissures can cause cusp restriction and impair valve opening. Thus, the natural height of the pseudo-commissure was usually respected when reimplanting the valve unless specific alterations to the cusp

geometry were desired. Table 2 describes the aortic root and annular interventions in this cohort.

Postrepair Echocardiography

After repair, transesophageal echocardiography was performed in all patients to assess the degree of AI, orientation of the regurgitant jet (if present), coaptation length, and coaptation height of the AV cusps. Coaptation length of at least 5 mm at the midportion of the free margin and a coaptation height above the AV annulus were prerequisites for a successful repair, and the presence of an eccentric residual AI jet was an indication for reexploration of the AV.¹⁵

Follow-up

Clinical follow-up was conducted through outpatient visits or 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. Transthoracic echocardiography was obtained in all patients pre-discharge and at regular intervals during follow-up. The closing interval for the study was between February 2009 and April 2009.

Statistical Analysis

Valve-related outcomes were defined as per published guidelines.¹⁶ Continuous data are presented as mean $\pm$ standard deviation or median (interquartile range) for nonparametric data. Failure time data on survival, reoperation, and recurrent AI are presented using Kaplan–Meier survival curves. Comparisons between groups for failure time data were performed using log-rank test. Statistical analyses were performed using SAS v. 9.1 (SAS Institute, Cary, NC). Graphs were constructed using GraphPad Prism 5.0 (San Diego, Calif).

RESULTS

Early Outcome

A second cardiopulmonary bypass run was necessary in 4 patients (3%) because of residual AI. Postrepair intraoperative transesophageal echocardiography demonstrated AI

TABLE 2. Intraoperative and postoperative data

Intraoperative data (n = 122)	
Concomitant procedures	16 (13)
Mitral valve repair	7 (6)
Aortic arch replacement	3 (2)
Coronary artery bypass	5 (4)
Ventricular septal defect closure	1 (0.8)
Cardiopulmonary bypass time (min, mean $\pm$ SD)	106 $\pm$ 39
Cardiac ischemia time (min, mean $\pm$ SD)	86 $\pm$ 34
BAV anatomy	
Type 0	24 (20)
Type I	98 (80)
Raphé repair techniques (n = 98)	
Shaving (no resection)	21 (17)
Resection with direct reapproximation	59 (48)
Resection with pericardial patch	18 (15)
Cusp prolapse repair techniques (n = 80)	
Free margin plication	23 (19)
Free margin resuspension (PTFE)	72 (59)
Aortic root and ascending aortic procedures	
Aortic root replacement	54 (44)
Reimplantation technique	41 (34)
Remodeling technique (partial)	10 (8)
Remodeling technique (complete)	3 (2)
Ascending aortic replacement	17 (14)
Subcommissural annuloplasty	51 (42)
Postrepair intraoperative TEE	
AI grade 0	92 (75)
AI grade I	29 (24)
Postoperative outcomes	
Mortality	0
Stroke	1 (0.8)
Reopening for bleeding	6 (5)
AV reintervention	5 (4)
Permanent pacemaker insertion	4 (3)
Predischarge echocardiography (n = 119)	
AI grade 0	59 (50)
AI grade I	51 (43)
AI grade II	9 (7)

PTFE, Polytetrafluoroethylene; TEE, transesophageal echocardiography; AV, aortic valve; AI, aortic insufficiency; SD, standard deviation.

grade 0 or 1 in 99% of patients and AI grade II in 1 patient. There was no in-hospital mortality. Postoperative complications are listed in Table 2. Five patients underwent AV reoperation during the index admission, of whom 3 presented relatively early in our experience (patient numbers 6, 8, and 9). Two patients presented with dehiscence of direct suture repair of a resected raphé and perforation, respectively, and 1 patient presented with an aorta–right ventricle fistula after a subcommissural annuloplasty. These 3 patients underwent re-repair. Two other patients presented with residual AI and underwent a Ross procedure. The details of all the AV reoperations are presented in Table E1. Predischarge echocardiography was available in 98% of patients and demonstrated AI grade 0 or 1 in 93% and AI grade 2 in 7%.

Clinical Follow-up

Clinical follow-up was complete in 100% of patients with a mean follow-up time of 61 ± 38 months (620 patient-years). Four patients died during follow-up. Two of these deaths were cardiac related (1 occurred after coronary surgery with a normally functioning AV), whereas the cause of death was unknown in the other 2 deaths. Overall survival was $97\% \pm 2\%$ at 8 years (Figure 2, A).

Seven AV reoperations occurred during the follow-up period at a mean follow-up time of 65 ± 30 months for valve stenosis (n = 1), endocarditis (n = 1), and recurrent AI (n = 5). Overall freedom from AV reoperation was $94\% \pm 2\%$ at 5 years and $83\% \pm 5\%$ at 8 years (Figure 2, B). Freedom from late AV reoperation (excluding the 5 early AV reinterventions) was $98\% \pm 2\%$ at 5 years and $87\% \pm 5\%$ at 8 years. Two of these patients underwent re-repair, giving a overall freedom from AV replacement of $96\% \pm 2\%$ and $90\% \pm 5\%$ at 5 and 8 years, respectively. The details of the reoperations are listed in Table E1.

Four embolic events (1 transient ischemic attack, 3 strokes) and no bleeding events occurred during the follow-up period, giving a linearized rate of 0.6% per patient-year and a freedom from thromboembolic and bleeding complications of $96\% \pm 2\%$ at 8 years. Two patients had endocarditis, 1 of whom underwent AV re-repair as described above and 1 of whom was treated medically. At last follow-up, 85% of patients were asymptomatic, 14% had New York Heart Association II symptoms, and 1% had New York Heart Association III symptoms.

Echocardiographic Follow-up

Echocardiographic follow-up was complete in 96% of patients with a mean follow-up time of 52 ± 35 months. A total of 11 patients presented with AI greater than 2+, giving a freedom from significant recurrent AI of $94\% \pm 3\%$ at 5 years. One patient presented with severe aortic stenosis during the follow-up period and underwent valve replacement as described above. Four additional patients presented with a mean valve gradient between 25 and 35 mm Hg, and all were asymptomatic except 1 patient (New York Heart Association class II).

Subgroup Analyses

Patients undergoing a root replacement procedure (either remodeling or reimplantation technique) had greater freedom from recurrent AI ($\geq 2+$) compared with those undergoing subcommissural annuloplasty or supracoronary aortic replacement for root stabilization (freedom from recurrent AI: $95\% \pm 5\%$ vs $80\% \pm 6\%$ at 5 years, $P = .03$, Figure 2, C).

Whether or not a pericardial patch should be used for cusp restoration after raphé resection remains controversial. Of 98 patients undergoing repair of a raphé, 19 patients had a pericardial patch used for cusp restoration. Use of a pericardial patch was associated with lower freedom from recurrent AI ($80\% \pm 11\%$ vs $85\% \pm 5\%$ at 5 years, $P = .02$, Figure 2, D). Cusp

FIGURE 2. Clinical and echocardiographic outcomes after BAV repair. A, At 5 years, overall survival was $97\% \pm 2\%$. B, Freedom from AV reoperation and replacement was $94\% \pm 2\%$ and $96\% \pm 2\%$ at 5 years, respectively. C, Patients undergoing aortic root replacement have a significantly lower recurrence of AI compared with those undergoing subcommissural annuloplasty with or without aortic root replacement ($*P = .03$). D, In patients requiring raphé repair, use of a patch was associated with greater recurrence of AI ($**P = .02$). AV, Aortic valve; SCA, subcommissural annuloplasty; AA, ascending aorta.

anatomy (type 0 vs type 1) was not predictive of AI recurrence ($P = .93$).

DISCUSSION

During the past 13 years, we have developed a systematic approach to BAV repair that addresses both cusp and ascending aortic pathology and is tailored to the specific anatomy encountered. In 122 consecutive patients, we have demonstrated that BAV repair is feasible and can be performed safely. These patients continue to have excellent long-term survival (97% at 8 years). Durability of the repair remains acceptable at midterm follow-up with freedom from late AV reoperation of 98% at 5 years and 87% at 8 years and freedom from recurrent AI ($>2+$) of 94% at 5 years. Freedom from thromboembolic and bleeding complications is excellent at 96% at 8 years. Analysis of the effect of surgical techniques on repair durability reveals that aortic root replacement is associated with less AI recurrence compared with subcommissural annuloplasty with or without ascending aortic replacement, and the use of a pericardial patch for raphé repair is associated with increased recurrent AI.

Despite attempts by several groups to repair regurgitant BAVs,¹⁷⁻²⁰ these repair techniques remain infrequently and heterogeneously applied. There are several possible reasons for this. First, the complex interaction between the valve cusp geometry and the functional aortic annulus that results in a competent AV is not well understood. Second, valve replacement with or without root replacement, not-

withstanding its limitations in this young population, is technically simpler to perform and produces reproducible results that are applicable to all patients.²¹ Third, and most important, there is limited and inconsistent information about the long-term outcomes of reparative procedures. Last, there is a lack of uniformity in the techniques being applied for BAV repair with important differences among different surgeons that causes some confusion and controversy regarding the approach to valve repair.

One principle that has emerged as a commonality is that BAV repair needs to address disease of the cusp and the functional aortic annulus and ascending aorta. Root replacement in this setting is performed not only to prevent the potentially fatal complications of aortic dissection and rupture but also to stabilize the repair procedure. Ongoing dilatation of the ventriculoaortic junction or the sinotubular junction can induce recurrent AI and render the cusp repair ineffective over the long term. Thus, if a BAV repair is to be attempted, an aggressive stance should be taken toward root replacement. The threshold for root replacement can therefore be different depending on whether the valve is to be repaired or replaced. In our series, the decision to replace the aortic root was based on size criteria and a visual assessment of the quality of tissue of the aortic wall. All patients with aortic root size greater than 4.5 cm and some patients with aortic root diameter less than 4.5 cm with fragile aortic wall tissue underwent root replacement. A similarly aggressive stance has been advocated in patients undergoing BAV replacement.²¹ Despite this aggressive stance, a root

FIGURE 3. Systematic approach to the repair of aortic root and cusp pathology in regurgitant BAVs.

replacement procedure was found to be protective against the development of recurrent AI in our series.

Another area of controversy relates to the use of a pericardial patch for valve repair. In the pediatric population, a pericardial patch is often necessary to reconstruct a commissure or extend a leaflet that has been damaged or destroyed by a previous balloon valvuloplasty procedure.²² In the adult patient, however, a patch may be used for 2 reasons. The first is for *cusp restoration* after the resection of a restrictive or calcified raphe, as was done in our series. A second option is to perform pericardial *cusp extension* to help increase the coaptation surface of the conjoint cusp by adding tissue to its free margin.²³ Although good short-term results have been reported with the latter approach, few data are available about mid- and long-term outcomes.²⁴ In our series, the use of a pericardial patch was a risk factor for recurrent AI. Possible reasons for this finding may be that the pericardium becomes fibrotic or calcified with time, which leads to insufficiency, or that the use of a patch is typically necessary in valves with a severely restrictive conjoint cusp that are more difficult to repair and are thus at greater risk for failure.

Our approach to BAV repair can be applied in a systematic manner to all patients presenting with isolated BAV insufficiency with or without aortic pathology (Figure 3). This approach relies on the understanding of the anatomic variations of bicuspid valves with their associated mechanisms of insufficiency. The first important question in this approach is whether the aortic root requires replacement. Both aortic root diameter and tissue quality are used to make this decision, and root replacement using the reimplantation technique is preferred when indicated. Next, cusp anatomy is evaluated. In a symmetric (type 0) valve, the cusp repair involves correction of leaflet prolapse by exclusion with or

without resection of excess cusp tissue along the free margin. This maneuver elevates the free margin, increases the coaptation height, and corrects the cusp prolapse. The tissue that needs to be excluded is often the thickened central portion of the leaflet. After the free margin plication (with or without resection), additional elevation of the cusp free margin can be achieved by resuspension with polytetrafluoroethylene suture. The objective is to have uniform coaptation of both cusps at approximately the midheight of the sinuses of Valsalva. In type 1 valves, the tissue quality of the conjoint cusp and the raphe are evaluated first. A restrictive and calcified raphe is treated with a parsimonious restriction, whereas a raphe that is prolapsing, mildly fibrotic, and accompanied by enough cusp tissue may be preserved and excluded with shaving and thinning of the tissue. Next, the adequacy of cusp tissue on the conjoint cusp is assessed. A type 1 prolapsing valve (Figure 1, B) typically has sufficient tissue, whereas a type 1 (restrictive) valve will often require addition of a pericardial patch. Next, the free margins of the 2 cusps are compared, and any residual or induced prolapse is corrected as described above for type 0 valves. Technical adjuncts for aortic root replacement in type 1 valves are used as described in the “Materials and Methods” section.

Important lessons have been learned from the early and late AV reoperations. Two early reoperations were for suture dehiscence after direct reapproximation in a raphe repair. In these cases, a tension-free repair is critical and the addition of a pericardial patch can facilitate that. Furthermore, during a root replacement with the reimplantation technique, the base of implantation of the conjoint cusp can be reduced, which increases the amount of cusp tissue available for coaptation. Another early AV reoperation was for a fistula

between the aorta and the right ventricle caused by injury to the membranous septum while performing subcommissural annuloplasty. Subcommissural annuloplasty in this region is thus performed at a higher level to avoid this complication. It can be performed lower in the fibrous portion of the subannular region to increase coaptation surface of the cusps. One late AV reoperation occurred in a patient who had undergone cusp repair for a type I valve with subcommissural annuloplasty and presented 6.5 years later with recurrent cusp prolapse and dilatation of the ventriculoaortic junction. Surgical inspection revealed dilatation of the muscular portion of the aortic annulus and migration of the subcommissural annuloplasty sutures and resulting prolapse of the conjoint cusp. This reinforces the idea that the aortic annulus in these patients can continue to dilate over time, and root replacement using the reimplantation technique should be used aggressively to stabilize the repair.

STUDY LIMITATIONS

This is a single-center experience using an approach and surgical techniques that have evolved over the past decade. In addition, follow-up echocardiographic information was not always obtained at Saint Luc Hospital, and thus a number of quantitative parameters (size of aortic annulus, root, and aorta) and descriptive features of recurrent AI (quantity, jet origin, and direction) were not systematically available and may have provided greater insight into the mechanisms of repair failures.

CONCLUSIONS

Repair of the BAV needs to address the pathology of the cusp and the functional aortic annulus and be tailored to the specific anatomy of the valve. Repair of regurgitant bicuspid valves is feasible and provides excellent freedom from valve-related complications. Freedom from reoperation and recurrent insufficiency are acceptable at midterm follow-up. Longer follow-up studies are required to determine the role of repair in the treatment of BAV insufficiency in young patients.

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Discussion

Dr Hartzell Schaff (Rochester, Minn). Congratulations to Drs Boodhwani and El Khoury and their associates for a beautiful presentation, which is useful to us because it shows the spectrum of operations in patients with BAV disease and is notable for the very low mortality.

The problem with the article in regard to application to clinical practice is that most patients with BAV disease present in 1 of 3 ways in terms of consideration of repair. Those are the patients with severe AV regurgitation and indication for operation is severe AR. Also, patients may have an enlarged aorta with only moderate AR. And a few patients present with both. I think it is important to

look at the results of valve repair in each of those categories. So the first question is, have you analyzed the outcome in regard to need for reoperation according to the severity of the AV regurgitation?

Dr Boodhwani. That is a very important question, and we have analyzed our data with regard to operative indication. I can show you a slide with regard to this. Essentially, we did not find any difference among the 3 modes of presentation and the long-term outcome with regard to recurrent AI or to AV reoperation, and we can view that data here.

(Slide) This is freedom from AV reoperation in patients who had AI only, AI plus dilatation, or dilatation only, and there is really no significant difference to speak of. Similarly, recurrent AI is similar between groups as well.

Dr Schaff. And knowing that you have these good results with repair of severe aortic regurgitation, has it changed your threshold for advising operation as it has, for example, with mitral regurgitation and the ability to repair the valve rather than replace it?

Dr Boodhwani. In fact, one of the common findings in the entire cohort of AV repair that we have accumulated over the years is that patients with greater dilatation of the left ventricular cavity have an increased risk of recurrent AI. So the longer you wait in terms of referring these patients to surgery, if they are to undergo repair, they will have a poorer longer-term result with the repair, and that may be an impetus to refer these patients for repair earlier. Having said that, there aren't convincing data in the literature to date to make such a recommendation, but these are some of the data that we are analyzing in our cohort.

Dr Schaff. One of the things that I noticed in your presentation and article that differs from our experience is the frequency with which you use aortic root replacement. We do see patients with dilatation of the sinus portion of the aorta who have BAV, but, more commonly, the patients at our clinic receive replacement of the ascending aorta with a supracoronary graft. What accounts for the high frequency of replacement of the sinus portion of the aorta in this series?

Dr Boodhwani. The first comment would be that this approach has evolved over 13 years of experience, and over that time period we have become more aggressive with root replacement, because we have observed that patients in whom the aortic root is stabilized with subcommissural annuloplasty alone tend to come back with some AI over the long term. So our threshold has decreased over time.

The second issue is that the criteria for root replacement, as you mentioned, is not size alone. Often you find a root that is 4 cm in size, but when you examine the aortic wall, particularly above the anterior cusp below the right coronary artery insertion, it is very fine. It can be occasionally translucent, and you can see the left ventricular muscle through it, and in those cases we opt to replace the root.

Dr Schaff. If you have a retracted cusp with scarring or enough calcification that you have to use pericardium, would you do that now or would you just replace the valve?

Dr Boodhwani. I think that has to take into account the broader context of the patient. If the patient is very interested in avoiding Coumadin and it is a young patient, we would be more aggressive with repair techniques. On the other hand, if it is an older patient who would be fine with a bioprosthetic valve, in those difficult cases we may opt for replacement.

Dr Jason Sperling (Ridgewood, NJ). Nothing to disclose. Thank you for that fantastic presentation. I wanted to make a comparison and perhaps a suggestion. These results are fantastic, and I hope we continue to build on them.

In mitral valve repair, when we do leaflet-based repairs, we still do an annuloplasty to protect that repair in the future so that annular changes don't ruin the nice leaflet repair. You are doing these leaflet-based repairs with what you are calling a subcommissural annuloplasty, but perhaps a mechanism of failure is that your annulus, your true annulus, the ventriculoaortic junction, is changing over time, and we noticed that in AI annuli, these are usually pretty big annuli to begin with and perhaps there is a predisposition for further dilatation over time. Why not, just as in a valve-sparing root type dissection, simply do a real aortic annuloplasty (which is possible)? You just cut your Dacron graft, do it over a Hegar dilator, and fix it in a particular configuration just like we do for a mitral valve. Do you think that that might enhance the durability of these repairs? Obviously, we want these repairs to be durable over time.

Dr Boodhwani. That is a great question. That is something that we have thought about a lot over the course of the years and over the course of our experience. To be honest, there isn't a particular device or technique that has currently been described to facilitate a complete annuloplasty of the ventriculoaortic junction. Effectively, that is performed using the aortic root reimplantation procedure, and that is part of the reason why we think we observed better results in that cohort. Earlier in our experience, and even occasionally now, we will use subcommissural annuloplasty with the same purpose, to try and stabilize the ventriculoaortic junction, but these are not as stable over time.

I think there is a need for developing a method for annuloplasty of the ventriculoaortic junction without having to replace the entire root. If you put a Dacron graft around the root and maintain the native root in place, you are potentially at risk for inducing more cusp prolapse because of the extensive amount of tissue that is within that Dacron graft.

Dr Sperling. I think it is possible to do an annuloplasty without actually replacing the sinus tissue with an extensive surgical dissection of the root down to the ventriculo-annular junction, again, just with a very small ring or a piece of Dacron over a dilator. I think it is something to consider.

Dr Boodhwani. Again, the anatomic limitations that prevent us are at the level of the membranous septum and the level of what would normally be a left-right commissure. We don't always dissect all the way down to the level of the ventriculoaortic junction. To place an annuloplasty device at that level, it may not be symmetric. But I agree with you that this concept needs to be further developed.

Dr Antonio Laudito (Wichita, Kan). My question is regarding the ascending aorta. You were talking about criteria of resection, but at the end you didn't really point out what size, considering your large experience, you are pushing your replacement. We know that with the bicuspid valve-ascending aorta, in case of dilatation, we are more aggressive than for the regular aneurysm. In your experience, how far down in size have you been going?

Dr Boodhwani. If a patient is presenting for isolated aortic dilatation, our threshold is still the that recommended by the American Heart Association and European Society of 5 cm, if that is the only pathology they have. However, if the patients are presenting

with AI and aortic dilatation, then there is the dual indication for referral to surgery. In those cases we are more aggressive. And, as I mentioned in the algorithm, anyone above 4.5 will definitely get a root replacement, whereas below 4.5, it is a judgment call based on the quality of the tissue.

Dr Robert Dion (*Genk, Belgium*). I am proud of what my team in Brussels has developed in this field. I have a short clinical comment related to my initial experience. When you have a type I with a common prolapsing leaflet, the first move would be to adapt this prolapsing leaflet, with or without eliminating the raphe, to the height of the other one. But I think we should reinforce the importance of first checking this other one, which should not be prolapsing at all! How often does it happen in your experience that you have to correct not only the obviously prolapsing one but also the

falsely normal one? I think it is an important point for people starting their experience in this field.

Dr Boodhwani. Excellent comment. In fact, an intervention on the nonconjoint cusp is required in a good proportion of patients (30%–40%), and the reason for that is 2-fold. One is that the nonconjoint cusp may in fact be prolapsing in addition to the conjoint cusp. Second, when you perform a root replacement procedure and reduce the ventriculoaortic junction diameter, you may induce prolapse of that leaflet. For both of those reasons, after any work has been done on the raphe or root, we examine both leaflets to make sure that the height of coaptation is at the midlevel of the sinuses of Valsalva, which is the physiologic valve coaptation level, and that both cusps are coapting at the same level, and those 2 are critical points for long-term function of this valve.

FIGURE E1. Cusp repair techniques. A, To assess adequacy of cusp tissue in type 1 bicuspid valves, gentle traction is applied on a 6-0 polypropylene suture that is passed on either side of the raphé. After raphé resection, the edges may be directly reapproximated if adequate tissue is present (B) or a pericardial patch is used for cusp restoration (C). D, Residual prolapse may be corrected by free margin resuspension using 7-0 polytetrafluoroethylene (white) suture.

TABLE E1. Early and late aortic valve reoperations

Year	Interval	Valve type	Aortic root intervention	Raphé repair	Other cusp repair technique(s)	Failure mode	Mechanism of failure	Type of AV reoperation
Early AV reoperations								
1997	day 7	1	SCA	Direct suture	FMP	AI	Suture dehiscence	Re-repair
1998	day 12	0	Remodeling; SCA	—	FMP	AI	Cusp prolapse	Ross procedure
1998	day 6	0	SCA	—	Patch on perforation	AI	Coaptation defect	Ross procedure
2006	day 10	1	SCA	Shaving	FMP; FMR	Fistula	Aorta–right ventricle fistula	Re-repair
2008	day 6	1	SCA	Shaving	FMP; direct suture of perforation	AI	Suture dehiscence	Re-repair
Late AV reoperations								
1996	8 y	1	AA replacement	Direct suture	Decalcification	AS	Calcification	Bioprosthesis
2000	7 y	1	SCA	Shaving	FMP; FMR	AH+AS	Cusp prolapse, calcification	Bioprosthesis
2001	2 y	1	SCA	Patch*	—	AI	Cusp prolapse	Ross procedure
2002	6 y	1	SCA	Direct suture	FMR	AI	Cusp prolapse (PTFE rupture), calcification	Ross procedure
2002	6.5 y	0	Remodeling; SCA	—	FMP	AI	Endocarditis	Re-repair
2002	6.5 y	1	SCA	Direct suture	FMR	AI	Cusp prolapse	Re-repair
2007	2 y	0	SCA	—	FMP; FMR; patch on perforation	AI	Cusp prolapse	Bioprosthesis

SCA, Subcommissural annuloplasty; AA, ascending aorta; AI, aortic insufficiency; AV, aortic valve; AS, aortic stenosis; PTFE, polytetrafluoroethylene; FMP, free margin plication; FMR, free margin resuspension (with 7-0 PTFE). *Tricuspid valve autograft patch was used in this patient.