Survival and reoperation pattern after 20 years of experience with aortic valve–sparing root replacement in patients with tricuspid and bicuspid valves

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ABSTRACT

Objective: Remodeling or reimplantation are established operative techniques of aortic valve–sparing root replacement. Long-term follow-up is necessary comparing tricuspid and bicuspid aortic valves.

Methods: A total of 315 patients (tricuspid, $n = 225$; bicuspid, $n = 89$, quadricuspid, $n = 1$; remodeling, $n = 101$, reimplantation, $n = 214$) were evaluated. Mean follow-up was 10.1 ± 5.6 and 6.4 ± 4.2 years for the remodeling and reimplantation group, respectively. Longest follow-up was 21.9 years with 99.2% completeness. Mean age of the patients was 55.9 ± 14.3 for the remodeling group and 48.9 ± 14.5 years for the reimplantation group.

Results: There was no significant difference in survival between the remodeling and reimplantation group ($P = .11$). Survival was comparable with the normal population in the reimplantation group ($P = .33$). Risk factors for late death were age, diabetes, and a greater New York Heart Association classification. Cumulative incidence of reoperation at 10 years was 5.8% for the reimplantation and 11.7% for the remodeling group ($P = .65$). Overall, there was no difference in the cumulative incidence of reoperation between tricuspid and bicuspid aortic valve patients ($P = .13$); however, a landmark analysis showed that in the second decade, the cumulative incidence of reoperation was greater in bicuspid aortic valve patients ($P < .001$). A total of 10 of 11 reoperated bicuspid aortic valves were degenerated.

Conclusions: The remodeling and reimplantation aortic valve–sparing root replacement techniques provided excellent long-term survival. Although the number of patients was relatively small, we provide some hints that in the second decade after the operation, especially in bicuspid aortic valve patients, the risk of reoperation may be increased, needing further evaluation. (J Thorac Cardiovasc Surg 2018;155:1403-11)

Cumulative incidence of reoperation after aortic valve–sparing root replacement.

Central Message

Aortic valve–sparing root replacement offers near-normal survival. However, the risk of reoperation is increased in the second postoperative decade, especially in patients with a bicuspid valve.

Perspective

Aortic valve–sparing root replacement techniques are appealing options to treat aortic root dilatation with or without aortic valve disease. Data of other groups regarding reoperation in the second decade after the operation in patients with a bicuspid aortic valve are required to obtain further insight in the probably more complex issue of bicuspid aortic valve and surgical treatment.

See Editorial Commentary page 1412.

In patients with aortic root aneurysm and macroscopic intact aortic valve leaflets, a valve-sparing root replacement may be indicated to prevent the shortcomings of replacement substitutes such as bioprostheses and mechanical valves. Such

repair operations are performed via 2 different techniques: remodeling (Yacoub)¹ and reimplantation (David).² Both are appealing aortic valve reconstructions warranting excellent hemodynamics, a low incidence of thromboembolism, and a low incidence of bleeding complications without the need for anticoagulation. The remodeling technique more physiologically preserves the aortic root distensibility and

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Received for publication July 5, 2017; revisions received Nov 15, 2017; accepted for publication Dec 5, 2017; available ahead of print Jan 17, 2018.

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0022-5223/\$36.00

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<https://doi.org/10.1016/j.jtcvs.2017.12.039>

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Abbreviations and Acronyms

BAV	= bicuspid aortic valve
CI	= confidence interval
CTD	= connective tissue disease
HR	= hazard ratio
TAV	= tricuspid aortic valve

movement of the aortic cusps.^{3,4} The clinical relevance of it, however, is unclear and may surface after only decades. Midterm results after both valve-sparing techniques have been reported to be excellent.⁵⁻⁹ For further judgment of this surgical principle, however, results of long-term, preferably life-long follow-up, are essential.¹⁰ Because survival and reoperation are the most relevant determinants for treatment quality, we present survival and reoperation patterns in patients after aortic valve-sparing root replacement, comparing the remodeling and reimplantation technique including the bicuspid aortic valve (BAV) and tricuspid aortic valve (TAV).

MATERIALS AND METHODS

From March 1994 to December 2016, 434 patients were consecutively operated on with the valve-sparing root replacement technique. After exclusion of patients with acute type A dissection, 315 patients (240 male, 51.1 ± 14.8 years, mean follow-up: 7.5 ± 5.0 years, reverse Kaplan–Meier method: median follow-up = 7.9 years (95% confidence interval [CI], 7.6–8.2 years), 2377.99 patient*years) were left for the study. The remodeling technique was performed in 101 patients; the reimplantation technique (Video 1) in 214 patients. A histogram with the annual number of the 2 procedures is depicted in Figure E1.

After approval by the ethical committee, patients' consent was obtained. Follow-up data were obtained between 2015 and 2017 via written questionnaires to the patients or their family doctors and via outpatient visits. The longest follow-up was 21.9 years, and the follow-up completeness—calculated according Clark and colleagues¹¹—was 99.2%. Preoperative data are presented in Table 1. The choice for either of the 2 techniques in the early days of valve-sparing surgery was related to the surgeon's preference, not to the dimensions of the annulus or other pathologies. Only if the annulus appeared enlarged (>28 –30 mm), a David annuloplasty¹² was performed in the remodeling group ($n = 16$). When we evaluated our results in 2008, we found that best hemodynamic results were obtained with the remodeling technique at lower annulus diameters and vice versa with the reimplantation technique.¹³ Since then, we have used both the techniques according to the annulus diameter.

In patients with an annulus diameter of 28 to 30 mm, the remodeling technique was applied, and in those with an annulus diameter >30 mm, the reimplantation technique was applied. Our operative technique has been reported in detail previously.³ Only leaflets that had a normal or near-normal macroscopic appearance with good pliability were accepted for repair. Additional cusp intervention was performed in 137 patients (Table 2). A central leaflet stitch was performed after root replacement in both remodeling and reimplantation. By this technique, the absolute parallelism of the leaflets with respect to the normal-appearing reference leaflet was judged and if additional length, which means some kind of prolapse, was present, this amount of additional length was centrally plicated with 6/0 U-stitches. In some cases, the thickened raphe of BAV type 1 left-right was resected and replaced with a triangular autologous glutaraldehyde preserved pericardial patch with 6/0 running suture.

VIDEO 1. Shown is a David reimplantation operation with a sinus prosthesis. In detail: transection of the aorta 1 cm above commissures, commissural suture 2/0 multifilament with pledget, dissection of sinus, sinus excision (noncoronary), left-coronary button preparation, preparation between aortic root and right ventricular outflow tract, sizing of the graft, preparing the sinus prosthesis, subannular implantation with multiple 2/0 multifilament Teflon pledget watertight U-stitches, knotting over Hegar dilator 24 or 26 (related to body surface area), commissure resuspension on the prosthesis with Teflon pledgets outside, sinus suture from inside the graft with 5/0 Prolene, knotting sinus suture over Teflon felt of commissure, left-coronary and right-coronary artery button anastomoses, central leaflet stitch for evaluating parallelism of the free edge of the leaflets, retracted right leaflet extension with glutaraldehyde prepared autologous pericardium, central plication of left coronary leaflet, postoperative 3-dimensional echocardiogram showing 3 sinuses, plication left leaflet and cusp extension of right leaflet, longitudinal echocardiogram showing central trace aortic insufficiency. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(17\)32847-7/fulltext](http://www.jtcvsonline.org/article/S0022-5223(17)32847-7/fulltext).

Intraoperative or predischARGE echocardiography revealed aortic insufficiency of grade none/trace in 287 patients (none, $n = 230$; trace, $n = 57$), mild to moderate in 1 patient, and unknown in 7 patients.

Statistical Analysis

For statistical analysis, the χ^2 test, Fisher exact test, the Mann–Whitney U test, and the Student t test were used where appropriate. Nominal and ordinal data are presented as absolute numbers and relative frequencies and continuous data as mean with standard deviations. Standardized differences were calculated via the definition recommended by Austin.¹⁴ The method of Benjamini and Hochberg¹⁵ was used to control the false discovery rate, resulting in a corrected significance level of .008. Calculations were performed with IBM SPSS Statistics (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0; IBM Corp, Armonk, NY) and SAS software (Version 9.4; SAS Institute Inc, Cary, NC).

Patient survival rates were analyzed by the Kaplan–Meier method and the log-rank test and reoperation by the cumulative incidence function adjusting reoperation for the competing risk of death and Gray's log-rank test. For patients living longer than 10 years, the reoperation rates in the remodeling and in the reimplantation group were calculated by the landmark analysis that is competing risk analysis, considering only patients with the occurrence with reoperation or death conditional on neither having occurred in the first 10 years. The Cox proportional hazards model was used to compare survival

TABLE 1. Perioperative characteristics of the patient population

Parameter	Reimplantation (n = 214)	Remodeling (n = 101)	Standardized difference	P value
Male sex	179 (83.6)	61 (60.4)	53.6	<.001
Age, y	48.9 ± 14.5	55.9 ± 14.3	−48.3	<.001
Bicuspid aortic valve	67 (31.3)	22 (21.8)	22.0	.082
Type 0	11 (5.1)	4 (4.0)		
Type 1	52 (24.3)	15 (14.9)		
Type 2	2 (0.9)	0		
Unknown	2 (0.9)	3 (3.0)		
Diabetes mellitus	6 (2.8)	5 (5.0)	−11.1	.339
Hypertension	135 (63.1)	70 (69.3)	−13.2	.312
Renal disease	2 (0.9)	1 (1.0)	−0.6	1
Serum creatinine, μ mol/L	83.5 ± 23.3	84.0 ± 27.8	−1.9	.667
Unknown	2	6		
Previous cardiac surgery	9 (4.2)	2 (2.0)	12.9	.513
Coronary artery disease	27 (12.6)	19 (18.8)	−17.1	.172
Peripheral artery disease	2 (0.9)	2 (2.0)	−8.7	.596
Cerebrovascular disease	8 (3.7)	7 (6.9)	−14.2	.258
Hyperlipidemia	56 (26.2)	30 (29.7)	−7.9	.588
Chronic pulmonary disease	10 (4.7)	3 (3.0)	8.9	.561
CTD	35 (16.4)	12 (11.9)	12.9	.397
Marfan	33 (15.4)	12 (11.9)		
Loeys-Dietz	2 (0.9)	0		
Mitral valve insufficiency $\geq$ grade I	43 (20.1)	28 (27.7)	−18.0	.149
Aortic valve insufficiency			1.9	.084
None/trace	27 (12.6)	13 (12.9)		
Mild	28 (13.1)	18 (17.8)		
Moderate	66 (30.8)	36 (35.6)		
Severe	93 (43.5)	31 (30.7)		
Unknown	0	3 (3)		
Annulus diameter, mm	31.9 ± 5.2	31.4 ± 7.5	7.6	.739
Unknown	86	72		
Sinus diameter, mm	49.6 ± 9.6	51.7 ± 11.2	−20.3	.200
Unknown	42	43		
STJ diameter, mm	41 ± 6.6	40.8 ± 8	2.1	.939
Unknown	95	82		
Ascending aorta diameter, mm	50.2 ± 12.4	56.3 ± 12.3	−49.9	<.001
Unknown	48	18		
LVEF			8.8	.012
>50%	174 (82.1)	66 (78.6)		
30%-50%	38 (17.9)	18 (21.4)		
Unknown	2	17		
NYHA				.007
Class I	91 (42.9)	21 (25.6)	37.1	
Class II	78 (36.8)	37 (45.1)	−17.0	
Class III	34 (16.0)	19 (23.2)	−18.0	
Class IV	9 (4.2)	5 (6.1)	−8.4	
Unknown	2	19		
Atrial fibrillation	11 (5.1)	9 (8.9)	−14.8	.220

CTD, Connective tissue disease; STJ, sinotubular junction; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

TABLE 2. Leaflet intervention in tricuspid and bicuspid aortic valves

	Tricuspid aortic valve	Bicuspid aortic valve
Leaflet intervention		
None	155 (68.9)	23 (25.8)
Plication	67 (29.8)	54 (60.7)
Pericardial extension	1 (0.4)	8 (9.0)
Plication + pericardial extension	1 (0.4)	3 (3.4)
Shaving	0	1 (1.1)
Plication + shaving	1 (0.4)	0

for the 2 procedures while also allowing for other variables. The aim of the Cox models was to allow for potential imbalances between the groups when comparing the reimplantation and remodeling procedures. We started by just allowing for differences between the reimplantation and remodeling procedures and then also included age, and then we looked at models including both the procedures, age, and one other variable.

The survival of patients in the study was compared with the predicted survival experience for equivalent members of the general population with respect to age and sex. The latter was determined with the German life-table, 2010/2012 (www.destatis.de). The subject-years method was used to compare the numbers of deaths for the 2 procedures with the expected (ie, average) numbers of deaths in the general population with the same age and sex profile. The standardized mortality ratio was calculated by the actual number of deaths divided by expected number of deaths based on the life-table.

RESULTS

Clinical Characteristics

Clinical characteristics are presented in Tables 3 and 4. Follow-up in the reimplantation group was 6.4 ± 4.2 years (range, 0-21.9 years) and 10.1 ± 5.6 (range, 0-19.8 years) in the remodeling group ($P < .001$).

Early Mortality

There were 5 early deaths overall (Table 4). In the reimplantation group, the causes for early death were sudden cardiac death, cardiac arrest with hemorrhagic shock, and hypoxic brain injury and in the remodeling the causes were septic shock with multiorgan failure and cardiogenic shock.

Late Mortality

A total of 38 late deaths occurred during the study time (Table 4). There were 6 late cardiac deaths in the remodeling group (3 patients with sudden cardiac death, 1 patient with heart failure, 1 patient with cardiac arrest after suspected myocardial infarction, and 1 patient with cardiac decompensation after pulmonary embolism). In the remodeling group, 9 late cardiac deaths occurred (2 patients with myocardial infarction, 2 patients with heart failure, 2 patients with acute aortic dissection, 1 patient with sudden cardiac death, 1 patient with cardiac arrest after descending aorta replacement and multiple bleedings, and 1 patient with cardiac decompensation after systemic inflammatory response syndrome).

Overall Mortality

The Cox proportional hazards model revealed a hazard ratio (HR) remodeling/reimplantation of 1.68 (95% CI, 0.89-3.19, $P = .111$), indicating no significant evidence of a difference in survival times (Figure 1). When we adjusted for age and sex, the estimated HR remodeling/reimplantation was smaller (HR, 1.23; 95% CI, 0.63-2.41, $P = .549$) and age was a significant risk factor for survival (HR per year: 1.04; 95% CI, 1.02-1.07, $P = .001$). In

TABLE 3. Operative details of the patients

Parameter	Reimplantation (n = 214)	Remodeling (n = 101)	P value
Elective surgery	196 (91.6)	87 (86.1)	.162
Additional procedures			
Partial or total aortic arch replacement	35 (16.4)	24 (23.8)	.124
Mitral valve intervention	8 (3.7)	7 (6.9)	.258
CABG	23 (10.7)	11 (10.9)	1
Aortic valve cusp intervention	107 (50.0)	31 (30.7)	.002
Size of prosthesis, mm			<.001
24	1 (0.5)	5 (5.0)	
26	8 (3.7)	14 (13.9)	
28	43 (20.1)	38 (37.6)	
30	123 (57.5)	38 (37.6)	
32	39 (18.2)	6 (5.9)	
Surgical data			
CPB time, min	218.1 $\pm$ 51.0	177.1 $\pm$ 47.1	<.001
Crossclamp time, min	180.0 $\pm$ 43.3	134.5 $\pm$ 43.9	<.001
Circulatory arrest			
No. of patients	52 (24.3)	51 (50.5)	
Circulatory arrest time, min	29.4 $\pm$ 23.3	22.2 $\pm$ 14.1	.022

CABG, Coronary artery bypass grafting; CPB, cardiopulmonary bypass.

TABLE 4. Follow-up data

Parameter	Reimplantation (n = 214)	Remodeling (n = 101)
Follow-up, y (mean $\pm$ SD and range)*	6.4 $\pm$ 4.2 0-21.9	10.1 $\pm$ 5.6 0-19.8
Mortality	17 (7.9)	26 (25.7)
Early mortality (≤ 30 d)	3 (1.4)	2 (2.0)
Late mortality (>30 d)	14 (6.5)	24 (23.8)
Cause of death		
Noncardiac	7 (50.0)	11 (45.8)
Cardiac	6 (42.9)	9 (37.5)
Unknown	1 (7.1)	4 (16.7)
Aortic valve reoperation	13 (6.1)	14 (13.9)
Aortic valve phenotype		
BAV, n	7	4
TAV, n	6	10
Finding at reoperation		
Leaflet degeneration (fibrotic shrinkage, calcification), n		
Total	11	6
BAV	7	3
TAV	4	3
Annulus dilatation, n		
Total	0	6
BAV	0	1
TAV	0	5
Endocarditis, n	TAV: 1	TAV: 1
Unknown, n	TAV: 1	TAV: 1
Hemodynamic indication for reoperation		
Stenosis	3	1
Insufficiency	9 (1 endocarditis)	11 (1 endocarditis)
Combined	1	2
Echocardiographic follow-up data, n*	104	61
Follow-up, y	5.9 $\pm$ 3.3	10.1 $\pm$ 4.4
Aortic regurgitation		
None/trace	60 (57.7)	23 (37.7)
Mild	37 (35.6)	29 (47.5)
Moderate	6 (5.8)	8 (13.1)
Severe	1 (1.0)	1 (1.6)
Mean pressure gradient, mm Hg	6.5 $\pm$ 4.1	6.0 $\pm$ 3.4

BAV, Bicuspid aortic valve; TAV, tricuspid aortic valve. *Only patients with echocardiographic follow-up >1 year.

addition, including other imbalances between groups (Table 1) in the multivariate Cox model did not reveal a difference in survival between the groups.

Survival was comparable with the normal population in the reimplantation group (standardized mortality ratio: 1.26 ± 0.60 , $P = .39$) but was lower in the remodeling group (standardized mortality ratio: 1.64 ± 0.63 , $P = .047$).

A multivariable Cox proportional hazards model using backward elimination including the variables listed in Table 1 revealed age (HR, 1.03; 95% CI, 1.01-1.06, $P = .02$), diabetes (HR, 3.04; 95% CI, 1.06-8.73, $P = .039$), and greater New York Heart Association classification (HR per increment 1.48; 95% CI, 1.04-2.12, $P = .032$) as risk factors for shorter survival time. There was not significant evidence of a difference in survival time between TAV and BAV patients ($P = .095$, Figure E2).

A total of 2 (4.3%) patients with connective tissue disease (CTD) died compared with 41 (15.3%) patients in the non-CTD group. In the remodeling group, 2 (15.5%) patients with annuloplasty and 24 (28.2%) patients without annuloplasty died.

Reoperation

There was no statistically significant difference regarding reoperation in both groups ($P = .65$, Figure 2). The cumulative incidence of reoperation at 10 years was 5.8% (95% CI, 2.8-12.0) for the reimplantation group and 11.7% (95% CI, 6.5-20.7) for the remodeling group. A total of 27 patients (BAV: $n = 11$; TAV: $n = 16$) needed a reoperation. The cumulative incidence of reoperation at 10 and 16 years was 5.3% (95% CI, 1.7-15.4) and 48.4% (95% CI, 27.7-74.1) in BAV patients and 9.8% (95% CI,

FIGURE 1. Kaplan-Meier survival curve for reimplantation and remodeling technique. The dashed line at 16 years represents the threshold of a statistical meaningful sample size.

5.9-16.0) and 10.9% (95% CI, 6.6-17.5) for TAV patients, respectively ($P = .13$) (Figure 3). The landmark analysis showed that the difference regarding reoperation between the BAV and TAV patients was only significant considering patients living longer than 10 years ($P < .001$) (Figure 3). Causes for reoperation were different (Table 4). Five (10.6%) reoperations had to be performed in patients with CTD compared with 22 (8.2%) patients without CTD. A total of 7 BAV patients and 2 patients with Marfan syndrome

needed reoperation in the reimplantation group and 4 BAV patients and 3 patients with Marfan syndrome in the remodeling group. A total of 10 of 11 reoperated BAV patients developed fibrotic tissue shrinkage or calcification of the leaflets causing predominantly aortic insufficiency with a lesser degree of stenosis. In the remodeling group, 3 (18.8%) patients with annuloplasty were reoperated and 11 (12.9%) patients without annuloplasty. Two patients were reoperated due to aortic valve endocarditis.

Morbidity

A stroke occurred in 8 (3.7%) patients of the reimplantation group and 2 (2.0%) patients in the remodeling group. Major bleeding events were reported by 10 (4.7%) patients in the reimplantation group and 4 (4.0%) patients in the remodeling group. Two (0.9%) in the reimplantation group and 2 (2.0%) patients in the remodeling group reported noncerebral embolic events.

DISCUSSION

In this retrospective study, we found that the survival and cumulative incidence of reoperation after the remodeling and reimplantation aortic valve-sparing root replacement techniques did not differ significantly. The same holds true for the probability of survival in TAV and BAV patients. However, more reoperations were necessary in BAV patients in the second decade after the reoperation, especially in the reimplantation group.

Normal anatomy warrants optimal function. Keeping this maxim in mind, the restoration of normal anatomy in general is appealing if the tissue is of favorable quality to expect

FIGURE 2. Cumulative incidence of reoperation for reimplantation and remodeling technique. The dotted line at 16 years represents the threshold of a statistical meaningful sample size.

FIGURE 3. Top: Cumulative incidence of reoperation for all BAV and TAV patients. Bottom: Landmark analysis: cumulative incidence of reoperation for BAV and TAV patients in 10-year survivors. The dotted lines at 16 years represent the threshold of a statistical meaningful sample size.

long-term function and durability. This is particularly important for the aortic valve, which plays a crucial role for left-ventricular to aortic coupling, allowing for passage of blood at rest and exercise with low energy loss.¹⁶ To achieve this goal, the aortic valve performs complex movements. It follows sophisticated 3-dimensional deformational dynamics, thereby reducing stress on the aortic cusps, minimizing transvalvular energy loss, and optimizing coronary flow.¹⁷⁻¹⁹

Preserving the aortic leaflets and restoring physiological root dynamics theoretically bear the potential to favorably influence long-term outcome of patients. The remodeling

technique includes the resection of the sinuses only and does not touch the interleaflet trigones and the annulus of the aortic valve, which seems to restore some kind of distensibility in this area in contrast the reimplantation technique, which incorporates the aortic valve into a rigid Dacron tube including the annulus of the aortic valve.^{3,4} This technique, however, corrects and prevents annulus dilatation and as such may also prevent the development of aortic regurgitation in the long term; therefore, we have preferred this technique in recent years.⁷

As one of the major determinants of treatment, quality survival after valve-sparing aortic root replacement was

excellent, being 72.6% (95% CI, 0.64-0.81) after 15 years, which is comparable with the normal population and the data of other groups.²⁰⁻²⁶ Reasons for this favorable outcome are not only the physiological concept of valve sparing but also the close follow-up of these patients. Survival in the reimplantation group was comparable with the normal population, and we found no difference in survival between the remodeling and the reimplantation groups. However, survival was lower than normal in the remodeling group. Whether this is related to the small number of patients, the lower ejection fraction and greater New York Heart Association classification, or the older age at the primary operation remains to be evaluated further.

The rate of reoperation was acceptable until 10 years postoperatively, as also reported by other groups,^{20,24,27} but thereafter we observed an obvious increase in the rate of reoperation especially in BAV patients compared with TAV patients, as shown by the landmark analysis. It must be considered, however, that the number of patients is relatively small and needs further evaluation with larger numbers of patients. Thus, our results are less favorable compared with those reported for the remodeling technique and BAV patients by Schneider and colleagues,²⁷ with a cumulative incidence of reoperation of 21.7% at 15 years. It is possible that in general our repair techniques in BAV patients were insufficient, although 10 of all reoperated BAV patients left the operating theater at primary repair with no aortic regurgitation and 1 patient with trivial aortic regurgitation. Furthermore, at primary operation, 10 of the 11 reoperated BAV patients had pliable leaflets, all were BAV type 1 left/right, and only in one a small calcification was present at the commissural remnant between the fused left and right coronary cusp, which was removed. In 5 patients, a plication of the leaflets was required, and in 6 patients none required additional cusp intervention. We found no systematic technical issue in our reoperated patients demonstrating that our kind of repair would lead to later fibrotic tissue changes and calcification (10 of 11). Whether more coaptation area by using pericardial leaflet augmentation²⁸ leads to better results remains speculative in as much as the use of pericardium for cusp repair was reported to be a risk factor for earlier reoperation.²⁵ More innovative repair techniques with greater coaptation area, avoidance of symmetrical prolapse, and more experience might result in better outcomes as reported by Schneider and colleagues,²⁷ with roughly 20% cumulative incidence of reoperation after 12 years. Furthermore, circumferential annuloplasty as described by Lansac and colleagues²⁹ or Schneider and colleagues²⁷ may function as an additional protective effect against aortic insufficiency and as such improve the outcome. Whether the observed degenerative process is related to a genetic background or whether the

unphysiological morphology and hemodynamics in patients with a BAV are causative remains unknown.

Another aspect that could have some influence on leaflet degeneration is the lack of sinuses in the reimplantation group, especially for BAV, leading to malrotation of the vortex behind the leaflets as recently shown by Oechtering and colleagues.³⁰ This degenerative process obviously accelerates in the second decade after surgery. These less-optimal results prompted us to rethink BAV for valve-sparing root replacement and in general may require a lot of more clinical and experimental research to shed light in this less-favorable issue. In view of these data, we more clearly inform our patients on the increased probability of reoperation in the second decade especially after BAV repair, confine the indication to absolute pliable leaflet tissue, perform more radical triangular resection of the thickened raphe with pericardial replacement extending on the free leaflet edges (right and left coronary cusps) to get more pliability and to increase coaptation area, and do not use cusps for repair that show any signs of beginning calcification. Together, this means some restriction in BAV indication. A Bio-Bentall procedure may be an alternative in those patients who do not like to take anticoagulation or a regular Bentall prosthesis with a mechanical valve. Nevertheless, the results with valve-sparing root repair are at least equivalent with a lower rate of composite events.^{31,32}

Limitations of the Study

This is a retrospective analysis and as such has a lot of flaws, weakening the comparability of the different groups. Nevertheless, it is a clinical series with relatively long follow-up time, providing us with some view on the results in the second decade. The number of patients is small, especially in the second decade; however, the number of events (late death and reoperation) is around 10% of the total cohort, and there is a clear trend for earlier degeneration in BAV compared with TAV, supporting the theoretical background of BAV as a less physiological valve. Because the follow-up time of the reimplantation procedure was shorter than for the remodeling group, it may explain the better survival compared with normal; however, this must be evaluated further.

In the early years, we did not use transesophageal echocardiography for analysis of intraoperative root dimensions and aortic valve function and defined the valve competent when the root was pressurized after removal of the aortic clamp and no dilatation of the left ventricle occurred. Since 2003, we have used intraoperative transesophageal echocardiography, which has allowed us to gain more qualitative data. However, in most patients, a transthoracic echocardiogram was performed pre-discharge, providing some information on the valve function. Furthermore, many patients had no records of aortic valve function and dimensions.

It is possible that there are certain, unknown patients with significant valve lesion needing reoperation because of the incomplete echocardiographic late follow-up. Whether those shortcomings influence results remains speculative in as much as almost all reoperated BAV patients showed fibrous and calcifications of the leaflets at reoperation, which is most likely an intrinsic process of the tissue of the leaflets.

CONCLUSIONS

In this series, survival was near normal in both the remodeling and reimplantation aortic valve-sparing root replacement techniques, and the cumulative risk of reoperation remained stable up to 10 years postoperatively. In the second decade, we observed an increase in reoperations, particularly in BAV patients. Although the number of BAV patients in the second decade is small, our findings caused us to closely rethink our indication and technique for BAV valve-sparing root replacement.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

The authors are thankful to Dr Derek Robinson for his support regarding the statistical analyses.

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Key Words: valve-sparing root replacement, remodeling, reimplantation, bicuspid aortic valve, long-term results

FIGURE E1. Histogram showing the annual numbers of the 2 operative techniques over time. The *dotted line* represents the time point when a change in our operative policy took place (see [Materials and Methods](#) section).

FIGURE E2. Kaplan-Meier survival curve for BAV and TAV patients. The *dashed line* at 16 years represents the threshold of a statistical meaningful sample size. Age at operation of TAV patients was 54.0 ± 14.8 years and that of BAV patients 44.0 ± 12.2 years.