Interactive CardioVascular and Thoracic Surgery 15 (2012) 644–650
doi:10.1093/icvts/ivs195 Advance Access publication 3 July 2012

Outcomes of aortic valve repair according to valve morphology and surgical techniques

Khalil Fattouch[a,b,*], Giacomo Murana[a], Sebastiano Castrovinci[a], Giuseppe Nasso[b], Claudia Mossuto[c], Egle Corrado[c], Giovanni Ruvolo[a] and Giuseppe Speziale[b]

[a] Department of Cardiac Surgery, University of Palermo, Palermo, Italy
[b] Department of Cardiovascular Surgery, GVM Care and Research, Anthea Hospital and Maria Eleonora Hospital, Bari and Palermo, Italy
[c] Department of Cardiology, University of Palermo, Palermo, Italy

* Corresponding author. Department of Cardiovascular Surgery, University of Palermo and GVM Care and Research MEH, Viale Regione Siciliana 1571, 90135 Palermo, Italy. Tel: +39-091-6554702: fax: +39-091-6554711; e-mail: khalilfattouch@hotmail.com (K. Fattouch).

Received 1 February 2012; received in revised form 19 March 2012; accepted 22 March 2012

Abstract

OBJECTIVES: The aim of this study was to assess the impact of aortic valve morphology and different surgical aortic valve repair techniques on long-term clinical outcomes.

METHODS: Between February 2003 and May 2010, 216 patients with aortic insufficiency underwent aortic valve repair in our institution. Ages ranged between 26 and 82 years (mean 53 ± 15 years). Aortic valve dysfunctions, according to functional classification, were: type I in 55 patients (25.5%), type II in 126 (58.3%) and type III in 35 (16.2%). Sixty-six patients (27.7%) had a bicuspid valve. Aortic valve repair techniques included sub-commissural plasty in 138 patients, plication in 84, free-edge reinforcement in 80, resection of raphe plus re-suturing in 40 and the chordae technique in 52. Concomitant surgical procedures were CABG in 22 (10%) patients, mitral valve repair in 12 (5.5%), aortic valve-sparing re-implantation in 78 (36%) and ascending aorta replacement in 69 (32%). Mean follow-up was 42 ± 16 months and was 100% complete.

RESULTS: There were six early deaths (2.7%). Overall late survival was 91.5% (18 late deaths). There were 15 (6.9%) late cardiac-related deaths. NYHA functional class was ≤II in all patients. At follow-up, 28 (14.5%) patients had recurrent aortic insufficiency ≥ grade II. The freedom from valve-related events was significantly different between bicuspid and tricuspid valve implantation ($P < 0.01$), between type I + II and type III ($P < 0.001$) dysfunction and between the chordae technique and plication, compared to free-edge reinforcement ($P < 0.01$). Statistically-significant differences were found between patients who underwent aortic valve repair plus root re-implantation, compared to those who underwent isolated aortic valve repair ($P = 0.02$).

CONCLUSIONS: aortic valve repair including aortic annulus stabilization is a safe surgical option with either tricuspid or bicuspid valves; even more so if associated with root re-implantation. Patients with calcified bicuspid valves have poor results.

Keywords: Aortic valve repair • Bicuspid aortic valve • Tricuspid aortic valve • Aortic annulus stabilization

INTRODUCTION

In the last two decades, aortic valve repair (AVR) has evolved into an accepted treatment for patients with aortic insufficiency (AI). Since the introduction of the functional classification of AI [1], results of AVR have improved and valve repair approaches have become good surgical options for isolated tricuspid as well as bicuspid AI [2–9]. Understanding the mechanisms of valve dysfunction and the aetiology of lesions has greatly aided surgeons in terms of technique development. Over the past decade, several surgical techniques have been described to correct AI according to the mechanisms of valve dysfunction. Aortic cusp prolapse has been corrected by techniques attempting to shorten the free margin of the cusp; the most commonly described techniques are plication (central or paracommissural), triangular resection, free-margin resuspension and our modified approach for free-margin resuspension, named ‘the chordae technique’ [2, 6, 7, 10, 11].

Despite increasing enthusiasm for AVR, the impact of aortic valve morphology (tricuspid or bicuspid) on long-term results is still poorly researched and the best surgical technique has not yet been established. We aimed to investigate the impact of aortic valve morphology and the different cusp repair techniques, including aortic annulus stabilization, on long-term AVR results.

MATERIALS AND METHODS

Patients

Since February 2003, 216 patients with AI underwent AVR in our institutions. Ages ranged from 26 to 82 years (mean 53 ± 15 years). Sixty-six (27.7%) patients received a replacement bicuspid aortic valve (BAV); among these, 16 patients had type 0 BAV, 40 patients had type 1 and 10 patients had type 2, according to Siever's classification [12]. Demographics and clinical data are illustrated in Table 1. The mechanisms of valve dysfunction according to functional classification were as follows: type I in 55 (25.5%) patients, type II in 126 (58.3%) and type III in 35 (16.2%). Concomitant aortic root or ascending aorta replacement procedures were carried out in 147 patients (68%) (Table 2).

Study endpoints

The study endpoints were (i) late incidence of recurrent AI, (ii) five-year freedom from cardiac-related deaths and (iii) valve-related events (recurrent AI ≥ grade II, aortic stenosis with mean gradient more than 25 mmHg and reoperation on the aortic valve).

Echocardiographic evaluation of the aortic valve lesions

Pre- and postoperative echocardiographic examinations were performed using the iE33 ultrasound imaging system (Philips Medical Systems, Veenpluis, Netherlands). Images from the transthoracic parasternal long-axis and short-axis views were acquired. Diameters of aorto-ventricular junction (AVJ), sino-tubular junction (STJ) and ascending aorta were routinely measured. The grade of AI was evaluated semi-quantitatively and was classified into four grades: mild (grade I), moderate (grade II), moderate-to-severe (grade III) and severe (grade IV). Using a fully-sampled matrix-array transoesophageal echocardiographic (TEE) transducer (X7-2T, Philips Medical Systems), intra-operative TEE examinations were performed in all patients, before and after weaning from cardiopulmonary bypass (diastolic blood pressure at 70 mmHg), to identify the mechanisms of valve dysfunction or residual aortic insufficiency. Aortic cusps and root lesions were categorized according to their functional classification [1]. Valve dysfunction was described by the cardiologist and confirmed by the surgeon intraoperatively into three main mechanisms: normal leaflet motion with dilatation of the aortic functional annulus or ascending aorta (type I), excess leaflet motion including cusp prolapse and free-edge fenestrations (type II) and restrictive leaflet motion with cusp retraction and/or cusp calcifications (type III).

Table 1: Demographic and preoperative patient characteristics

Variables	No of patients (%)
Age (years)	53 ± 15
Male gender	166 (76.8%)
Diabetes	22 (10%)
COPD	21 (9.7%)
Hypertension	101 (46.7%)
Creatinine >1.5 mg/dl	11 (5%)
Angina	6 (2.7%)
Atrial fibrillation	12 (5.5%)
Bicuspid valve	66 (27.7%)
Type 0	16 (24.2%)
Type 1	40 (60.6%)
Type 2	10 (15%)
NYHA functional class	
II	125 (57.8%)
III	36 (16.5%)
IV	24 (11%)
Ascending aortic pathology	
Atherosclerotic aneurysm	55 (25.4%)
Degenerative	111 (51.3%)
Marfan	36 (16.6)
Type of valve dysfunction	
Type I	55 (25.5%)
Type II	126 (58.3%)
Type III	35 (16.6%)
Grade of AI	
Moderate-to-severe	58 (27%)
Severe	158 (73%)

COPD: Chronic obstructive pulmonary disease; NYHA: New York Heart Association; AI: aortic insufficiency.

Table 2: Intraoperative data and surgical techniques

Variables	No of patients
Cusp repair	
Plication	84 (38.8%)
Free-edge reinforcement (Gore-Tex)	80 (37%)
Chordae technique	52 (37.5%)
Triangular resection of raphe + re-suturing	40 (18.5%)
Procedures on functional aortic annulus	
David's procedure	78 (36%)
Ascending aortic replacement (STJ remodelling)	69 (32%)
Subcommissural plasty	138 (63.8%)
David's procedure + cusp repair	20 (9.2%)
Ascending aortic replacement (STJ remodelling) + subcommissural plasty	41 (18.9%)
Associated surgical procedures	
CABG	22 (10%)
Mitral valve repair	12 (5.5%)
Intraoperative	
Bypass time (min)	101 ± 46
Cross-clamp time (min)	87 ± 32

STJ: Sinotubular junction; CABG: Coronary artery bypass grafting.

Surgical technique

In all patients, the chest was opened by median sternotomy, with cannulation of the aorta and the right atrium for normothermic cardiopulmonary bypass. After aortic cross-clamping and aortotomy, cardioplegic arrest was induced by infusion of blood cardioplegia directly in to the coronary ostia. During cardiac arrest, all the components of the aortic root were inspected: in particular the morphology of the aortic cusps was assessed.

Our systematic approach for aortic valve analysis has been previously described [11]. The criteria for selecting the method of aortic valve repair are closely related to the type of valve dysfunction based on functional classification. We used a systematic surgical approach, beginning with valve analysis by TEE followed by intraoperative inspection. Subcommissural plasty was performed using a 2-0 Ticron suture, reinforced with Teflon

ORIGINAL ARTICLE

pledgets (DuPont, Wilmington, DE, USA) placed at the base of the interleaflet triangle to treat annular dilatation. For cusp prolapse, we used the cusp plication technique, free-edge reinforcement with Gore-Tex suture or the chordae technique [11]. The cusp plication technique was performed using a 6-0 Prolene suture (Ethicon Inc, Hamburg, Germany) placed in the central zone of the elongated free margin of the cusp and extended perpendicularly from the free margin about 5 mm through the belly of the leaflet to decrease distension. If excess tissue was found in the plication zone, small resection was performed to avoid postoperative restrictive leaflet motion. The free-edge reinforcement technique was performed using a CV-6 or CV-7 Gore-Tex suture (W. L. Gore and Associates, Flagstaff, AZ, USA), passed in running fashion over and over, along the entire length of the free margin. Free margin shortening was obtained by applying tension on both suture arms, which were locked at the level of the commissures when an appropriate correction had been reached. The chordae technique was performed by a free-margin reinforcement using three Gore-Tex sutures. The first suture was placed at the free margin of the cusp, starting from one commissure to another; the second was placed at the free margin of the leaflet from one commissure to the noduli of Arantius and passed through the ascending aorta at the level of the STJ; finally, a third suture was placed in the same manner from the opposite commissure of the leaflet to the noduli of Arantius and then through the aorta at the same level as the second suture. On completion, two suture arms are present at each commissure and at the level of the STJ in the outer side of the aortic wall. Calcified raphe in bicuspid aortic valves was treated by resection and re-suturing using a 6-0 Prolene suture or pericardial patch. STJ reconstruction was performed with supracoronary ascending aorta replacement, thus providing additional stabilization of functional aortic annulus. Finally, concomitant surgical procedures were performed as necessary (coronary artery bypass grafting, mitral valve repair, etc.).

Follow-up data

Follow-up was performed at six-month intervals through our outpatient clinics. Pre- and postoperative clinical status was determined according to NYHA functional class for heart failure symptoms and the CCS for angina. Clinical and echocardiographic follow-up data were obtained in all patients and were 100% complete. Data were obtained from our computerized outcome data collection instrument. The mean follow-up time was 42 ± 16 months and ranged between 3 and 82 months. The closing interval during follow-up was 2–3 months.

Statistical analysis

Data are presented as the mean ± standard deviation for continuous variables or as a percentage for categorical variables. Cox regression analysis was used to identify predictors for aortic valve-related events. Where appropriate, hazard ratios were computed with the 95% confidence intervals. The actuarial survival and other time-related events were analysed using the Kaplan-Meier survival curves. The log-rank test was used to compare statistical significance level. Values of $P < 0.05$ were considered statistically significant. SPSS statistical software (SPSS Inc, Chicago, IL) was used.

RESULTS

Combined AVR plus root or ascending aorta replacement was performed in 147 patients while isolated AVR was performed in 69. Cusp repair included plication in 84 cases, free-edge reinforcement in 80 and the chordae technique in 52. Triangular resection of calcified raphe, with direct re-suturing or patch reconstruction, was performed in 40 patients receiving bicuspid valves; in this cohort of patients, free-edge reinforcement with a Gore-Tex suture or the chordae technique were added for cusp resuspension. All data are listed in Table 2.

Early outcomes

The overall incidence of in-hospital deaths was 2.7% (six patients). Three patients died from pneumonia, one from perioperative myocardial infarction, one from stroke and one from bowel ischaemia. Re-exploration for bleeding was needed in 12 (5.5%) patients.

One patient had a supra-annular aortic wall laceration at the level of subcommissural plasty, between the right coronary cusp and non-coronary cusp, with a right ventricular wall haematoma and right coronary artery compression requiring CABG. A second pump-run was required in 18 (8.3%) patients to correct residual AI. Mechanisms of remaining AI were residual cusp prolapse in 12 patients and functional annulus dilatation in six. Mean aortic cross-clamp and cardiopulmonary bypass times were 101 ± 46 and 87 ± 32 minutes, respectively.

The mean postoperative hospital stay was 9 ± 2 days. At hospital discharge, echocardiographic examinations showed a trivial central residual AI in 15 (7%) patients.

Late outcomes

There were 18 late deaths, including 15 (6.9%) cardiac-related deaths. Causes of late deaths were heart failure in six patients, sudden death in five, cancer in three, malignant arrhythmias in two, stroke in one and one unknown. Overall survival rate was 91.5% (Fig. 1(A)).

At follow-up a total of 28 (14.5%) patients had recurrent moderate-or-greater AI. Among these, 10 (5.2%) patients had moderate-to-severe AI and needed re-do aortic valve operations at 1, 2, 4 and 5 years after the first procedure. Causes of severe AI were cusp re-prolapse in eight patients and suture disruption in two. Eighteen patients with moderate AI were in NYHA functional class I or II and still under clinical follow-up. Three patients (1.3%) had moderate aortic stenosis and two (0,9%) had endocarditis. No thromboembolic valve-related events were found. Freedom from reoperation and from recurrent AI rates are illustrated in Figure 1(B).

Freedom from valve-related events was significantly different between patients receiving bicuspid and tricuspid valves ($P < 0.01$) (Fig. 2(A)). Statistically-significant differences were found for the subgroup of patients with type 2 bicuspid valve (Fig. 2 (B)). Repair of type III AI had worse results, compared to type I and type II ($P < 0.001$) (Fig. 3(A)). The chordae technique and the cusp plication approach produced better results, compared to cusp free-edge reinforcement alone ($P < 0.01$) (Fig. 3(B)).

Isolated AVR, with either bicuspid or tricuspid valves, produced worse results, compared with combined AVR and

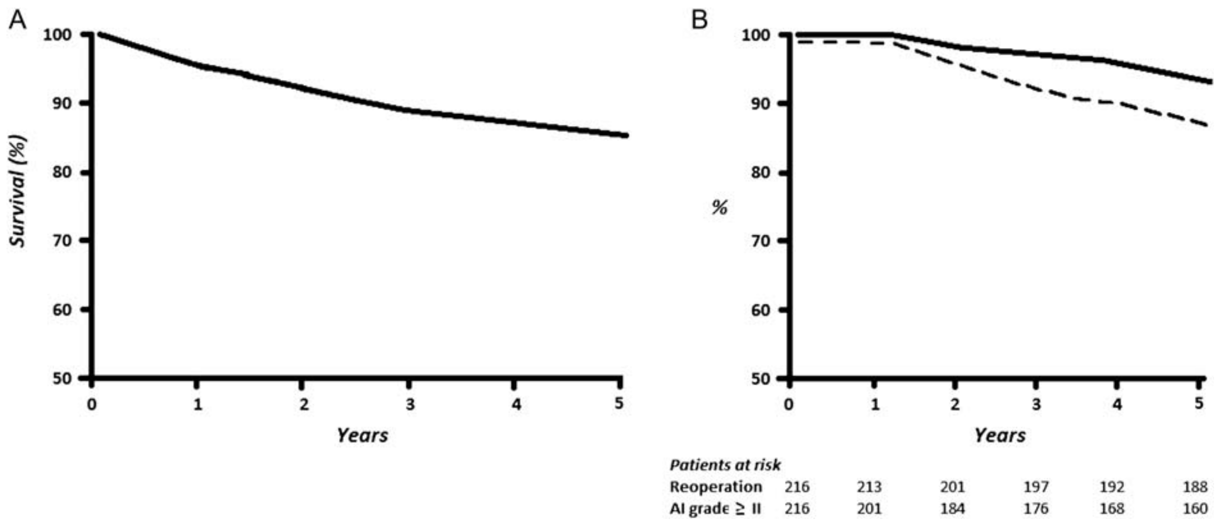


Figure 1: (**A**) Overall survival rate (±SD) for all patients. (**B**) Freedom from reoperation on aortic valve (solid line) and from aortic valve insufficiency grade equal to or greater than moderate (dashed line).

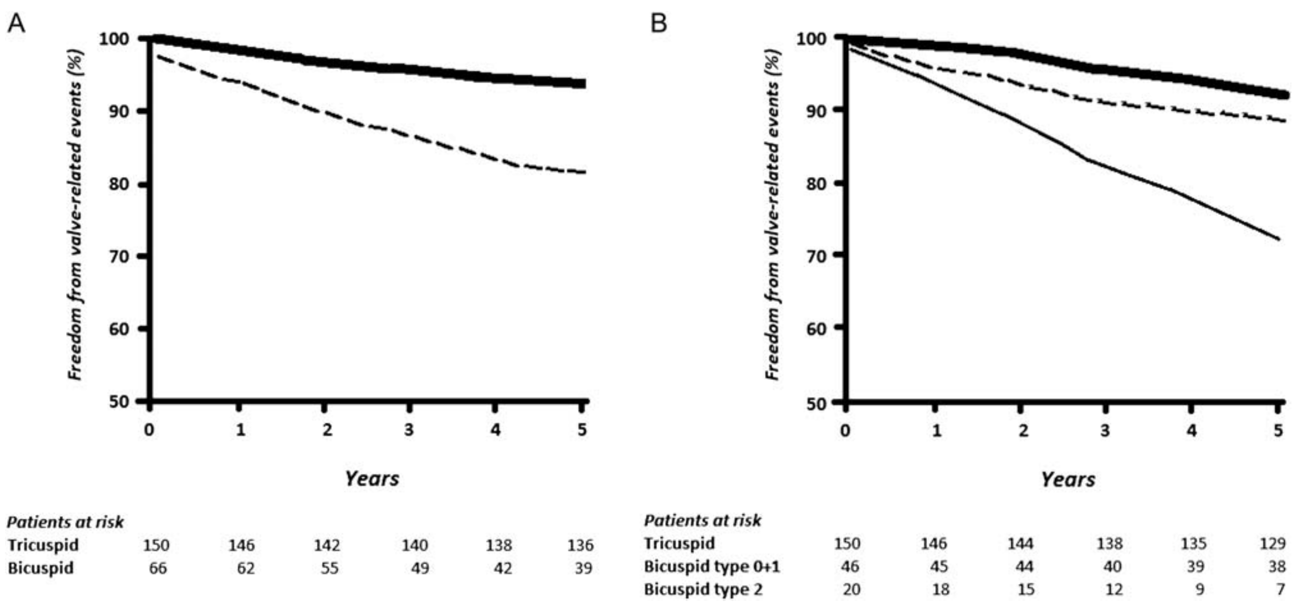


Figure 2: (**A**) Freedom from aortic valve-related events between patients with tricuspid (solid line) and bicuspid (dashed line) valve ($P < 0.01$). (**B**) Freedom from aortic valve-related events for patients with tricuspid valve (solid line), bicuspid type 0 + 1 (dashed line) and bicuspid type 2 (fine line).

stabilization of all components of the functional aortic annulus (David's reimplantation procedures or replacement of the ascending aorta with STJ remodelling plus subcommissural plasty) (Fig. 4(A) and (B)).

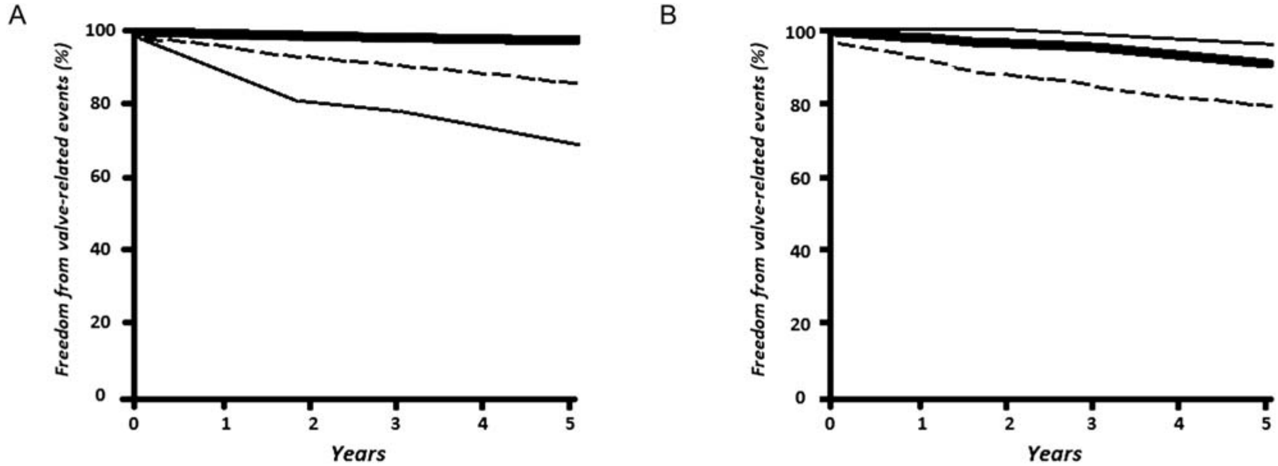
By Cox regression analysis, bicuspid type 2 aortic valve ($P = 0.0003$, HR = 10, CI = 6.6–92), type III dysfunction ($P = 0.001$, HR = 7.0, CI = 1.9–50), free-edge reinforcement ($P = 0.01$, HR = 5, CI = 1.7–15) and isolated AVR ($P = 0.01$, HR = 8, CI = 2.1–35) were identified as predictors for recurrent AI equal to or greater than grade II and aortic valve reoperation (Table 3).

DISCUSSION

Interest in aortic valve repair and the aortic valve-sparing operation has been growing for more than a decade [13–15]. Several surgeons tried to develop a successful repair technique for AI [3,16–20]. Unfortunately, in the first era, the surgical results of AVR were less satisfactory than mitral valve replacement, since repair is hampered by the lack of valve tissue available to achieve a good competence. Recently, thanks to better knowledge of the anatomy and function of the aortic valve and improvements in surgical techniques, AVR is now considered the best surgical approach for patients with AI in many centres [4, 20–24].

In the current study, we analysed the AVR outcomes, comparing the different leaflet repair techniques and the surgical approaches for the ascending aorta and aortic root. We also compared the repair results between tricuspid and bicuspid valves. In our series, five-year freedom from reoperation and from recurrent AI for the entire population were 94.8 and 85%, respectively (Fig. 1(B)). Five-year freedom from valve-related events was significantly different between patients with tricuspid

ORIGINAL ARTICLE



Patients at risk	0	1	2	3	4	5
type I	55	54	52	52	50	49
type II	126	115	110	108	101	99
type III	35	29	25	20	15	11

Patients at risk	0	1	2	3	4	5
Plication	84	81	79	72	68	65
Resuspension	80	76	71	65	56	52
Chordae technique	52	52	51	50	49	48

Figure 3: (**A**) Freedom from aortic valve related-events according to functional classification of aortic valve regurgitation. type I (solid line), type II (dashed line) and type III (fine line). (**B**) Freedom from aortic valve-related events according to cusp repair techniques. Plication (solid line), valve resuspension with Gore-Tex (dashed line) and the chordae technique (fine line).

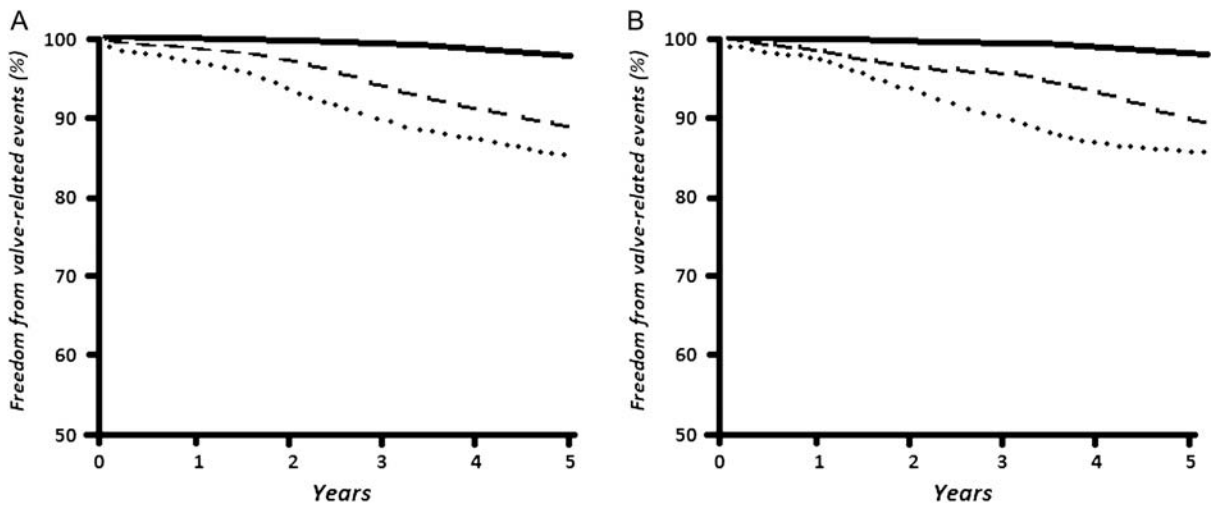


Figure 4: (**A**) Tricuspid. (**B**) Bicuspid. Freedom from aortic valve-related events for patients who underwent aortic valve-sparing (solid line), ascending aorta replacement (dashed line) and isolated aortic valve repair (dotted line).

and bicuspid valve (92.3 and 73.2%, $P < 0.01$): this can be explained because there are poor outcomes in patients with type 2 bicuspid aortic valves (calcified raphe, poor cusp quality and commissural fusion) (Fig. 2(A)). Patients with types 0 and 1 bicuspid aortic valves have good long-term results similar to those with tricuspid valves (Fig. 2(B)). Given good leaflet quality and non-extensive calcifications, results showed that AVR with bicuspid valve is an easy and safe procedure and must be encouraged. Presence of one raphe, even if calcified, may be treated successfully by raphe resection, shaving and direct cusp re-suturing. If a wide leaflet gap is present after raphe resection, pericardial patch reconstruction may be used.

We are in agreement with the studies that have thought it easier to repair bicuspid valves because only a single coaptation line has to be appreciated in contrast to the more complex interference of three coaptation lines of tricuspid valves [6, 8, 9, 21].

Casselman *et al*. tried to determine the durability of repair of bicuspid aortic valves with leaflet prolapse and to identify predictive factors for repair failure [6]. They studied 94 patients: triangular resection was used in 66 patients and plication in 28. Freedom from reoperation was found in 95%, 87% and 84% of cases at 1, 5 and 7 years respectively. The risk of reoperation was highest immediately after operation and fell rapidly to approximately 2% per year and less than this after two years. The only risk factor identified was the presence of residual AI on immediate intraoperative post-repair (trace to mild in 35 cases). In our series, five-year freedom from valve-related events for tricuspid valve, bicuspid types 0 plus 1 and bicuspid type 2 were 97.8%, 92.5% and 72.4%, respectively (Fig. 2(A) and (B)).

Schäfers *et al*. published their experience in bicuspid and tricuspid aortic valve repair [2, 9]. Valve reconstruction primarily consisted of correction of cusp prolapse by plication or

Table 3: Predictors for valve-related events in all patients by Cox regression analysis

Variables	*P* value	HR	95% CI
Bicuspid type 2	0.0003	10	6.6–92
Type III dysfunction	0.001	7.0	1.9–50
Free-edge reinforcement	0.01	5	1.7–15
Isolated AVR	0.01	8	2.1–35

HR: Hazard ratio; CI: Confidential interval; AVR: aortic valve repair.

triangular resection of the fused cusps. Calcification of the raphe or deficiency of cusp tissue was treated by excision and insertion of glutaraldehyde-fixed autologous pericardium. Five-year freedom from AI grade II or greater was 95.5% after remodelling, 92.1% after isolated valve repair and 91% after valve repair plus ascending aortic replacement. Five-year freedom from reoperation was 97% after remodelling and 94.3% after valve reconstruction only. The pioneering work of Schäfers' group showed that the results of AVR were improved when all components of the aortic root were stabilized by remodelling techniques. In our series, five-year freedom from valve-related events for patients who underwent AVR plus re-implantation, AVR plus ascending aortic replacement, and isolated AVR were, respectively, 97.8%, 88.5% and 86.5% for tricuspid valve and 98.5%, 89.6% and 84.2% for bicuspid valve (Fig. 4(A) and (B)). We showed that the functional aortic annulus stabilization by aortic root reimplantation technique give better results in terms of late recurrent AI, compared with isolated subcommissural plasty, with or without ascending aorta replacement, using either tricuspid or bicuspid aortic valves (Fig. 4). The reason is that reimplantation techniques stabilize all components of the functional aortic annulus (nadir of the valve, STJ and the continuity between both), compared with isolated subcommissural plasty.

De Kerchove *et al*. published their results of cusp prolapse repair, where freedom from reoperation at five years was 100% for plication, 96% ± 4% for resuspension and 93% ± 7% for plication plus resuspension [10]. The authors found that both cusp plication and resuspension are safe and durable techniques to correct prolapse. However, plication is preferred by the authors because of its lower risk of overcorrection. Our data found a five-year freedom from valve-related events of 98.2% for the chordae technique, 97.8% for plication and 90.2% for resuspension by free-edge reinforcement. We think that, in patients with poor cusp quality with redundant leaflet and severe prolapse, isolated cusp free-edge reinforcement could result in early valve repair failure, with cusp re-prolapse due to slipping of the Gore-Tex suture. In this cohort of patients we suggest the plication-plus-resuspension approach or the chordae technique.

In conclusion, AVR can be performed with low operative risk and excellent long-term results, either with tricuspid or bicuspid aortic valves. Results were better in type 0 and -1 bicuspid aortic valves, compared with type 2. Patients with type I and II functional AI have better results compared to type III. Cusp plication or the chordae technique appears to be much safer than isolated free-edge reinforcement. The approach of aortic valve-sparing surgery with reimplantation improves long-term outcomes. Although isolated AVR had poorer results than the techniques of stabilization of the annulus, our long-term results in this subgroup of patients are satisfactory. Finally, as regard to bicuspid type 2 aortic valve and to tricuspid aortic valve with type III dysfunction, we nowadays recommend aortic valve replacement. Isolated aortic valve repair must be performed, in our opinion, in the normal aortic root and ascending aorta. On the other hand, we recommend aggressive replacement of the ascending aorta with sinotubular junction remodelling and aortic valve reimplantation for root dilatation because of improved long-term results of aortic valve repair.

Conflict of interest: none declared.

REFERENCES

[1] El Khoury G, Glineur D, Rubay J, Verhelst R, d'Acoz Y, Poncelet A *et al*. Functional classification of aortic root/valve abnormalities and their correlation with etiologies and surgical procedures. Curr Opin Cardiol 2005; 20:115–21.

[2] Langer F, Aicher D, Kissinger A, Wendler O, Lausberg H, Fries R *et al*. Aortic valve repair using a differentiated surgical strategy. Circulation 2004;110 (suppl II):II-67–II-73.

[3] Cosgrove DM, Rosenkranz ER, Hendren WG, Bartlett JC, Stewart WJ. Valvuloplasty for aortic insufficiency. J Thorac Cardiovasc Surg 1991;102: 571–77.

[4] Carr JA, Savage EB. Aortic valve repair for aortic insufficiency in adults: a contemporary review and comparison with replacement techniques. Eur J Cardiothorac Surg 2004;25:6–15.

[5] Minakata K, Schaff VH, Zehr JK, Dearani AJ, Daly CR, Orszulak AT *et al*. Is repair of aortic valve regurgitation a safe alternative to valve replacement? J Thorac Cardiovasc Surg 2004;127:645–53.

[6] Casselman FP, Gillinov AM, Akhrass R, Kasirajan V, Blackstone EH, Cosgrove DM. Intermediate-term durability of bicuspid aortic valve repair for prolapsing leaflet. Eur J Cardiothorac Surg 1999;302–8.

[7] Ahn H, Kim K-H, Kim YJ. Mid-term result of leaflet extension technique in aortic regurgitation. Eur J Cardiothorac Surg 2002;465–69.

[8] El Khoury G, Vanoverschelde JL, Glineur D, Pierard F, Verhelst RR, Rubay J *et al*. Repair of bicuspid aortic valves in patients with aortic regurgitation. Circulation 2006;114(suppl I):I-610–16.

[9] Schafers HJ, Aicher D, Langer F, Lausberg HF. Preservation of the bicuspid aortic valve. Ann Thorac Surg 2007;83:S740–45.

[10] De Kerchove L, Boodhwani M, Glineur D, Poncelet A, Rubay J, Watremez C *et al*. Cusp prolapse repair in tri-leaflet aortic valves: free margin plication and free margin resuspension techniques. Ann Thorac Surg 2009;88: 455–61.

[11] Fattouch K, Sampognaro R, Bianco G, Navarra E, Moscarelli M, Speziale G *et al*. Implantation of Gore-Tex chordae on aortic valve leaflet to treat prolapsed using 'The chordae technique': Surgical aspects and clinical results. Ann Thorac Surg 2008;85:2019–25.

[12] Sievers HH, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. J Thorac Cardiovasc Surg 2007;133: 1226–33.

[13] Jeanmart H, De Kerchove L, Glineur D, Goffinet JM, Rougui I, Van Dyck M *et al*. Aortic valve repair: The functional approach to leaflet prolapse and valve-sparing surgery. Ann Thorac Surg 2007;83:S746–51.

[14] Le Polain de Waroux JB, Poleur AC, Goffinet C, Vancraeynest D, Van Dyck MRobert A *et al*. Functional anatomy of aortic regurgitation : Accuracy, prediction of surgical reparability and outcome implications of transoesophageal echocardiography. Circulation 2007;116 (suppl I):I-264–69.

[15] David TE, Feindel CM, Webb GD, Colman JM, Armstrong S, Maganti M. Long-term results of aortic valve sparing operations for aortic root aneurysm. J Thorac Cardiovasc Surg 2006;132:347–54.

[16] Lillehei CW, Gott VL, DeWall RA, Varco RL. The surgical treatment of stenotic and regurgitant lesions of the mitral and aortic valves by direct vision using pump oxygenator. J Thorac Cardiovasc Surg 1958;35:154–91.

[17] Mulder DG, Kattus AA, Longmire WP. The treatment of acquired aortic stenosis by valvuloplasty. J Thorac Cardiovasc Surg 1960;40:713–43.

[18] Starr A, Menashe V, Dotter D. Surgical correction of aortic insufficiency associated with septal ventricular defect. Surg Gynecol Obstet 1960;111: 71–76.

[19] Carpentier A. Cardiac valve surgery: the French correction. J Thorac Cardiovasc Surg 1983;86:323–37.

[20] Duran CMG. Aortic valve repair. J Thorac Cardiovasc Surg 1994;3:64–68.
[21] Haydar HS, Guo-Wei He, Hagop H, Mc Irvin D, Douglas H, Starr A. Valve repair for aortic insufficiency: surgical classification and techniques. Eur J Cardiothorac Surg 1997;11:258–65.
[22] Duran CMG. Present status of reconstructive surgery for aortic valve disease. J Card Surg 1993;8:443–452.
[23] Rao V, Van Arsdell GS, David TE, Azakie A, Williams WG. Aortic valve repair for adult congenital heart disease. A 22-year experience. Circulation 2000;102(suppl. III):III 40–III 43.
[24] Al Halees Z, Gometza B, Al Sanei A, Duran C. Repair of moderate aortic valve lesions associated with other pathology: an 11-year follow-up. Eur J Cardiothorac Surg 2001;20:247–51.