# Long-Term Outcomes after Aortic Valve Repair and Associated Aortic Root Reconstruction

Marek J. Jasinski[1], Radoslaw Gocol[1], J. Scott Rankin[2], Marcin Malinowski[1], Damian Hudziak[1], Marek A. Deja[1]

[1]*Department of Cardiac Surgery, Medical University of Silesia, Katowice, Poland,* [2]*Department of Cardiac Surgery, Vanderbilt University, Nashville, TN, USA*

*Background and aim of the study:* **The advantages of aortic valve repair and root reconstruction include the maintenance of natural valve hemodynamics and an avoidance of prosthetic valve-related complications. However, the general acceptance of valve reconstruction currently may be limited by a paucity of long-term follow up data from only a few centers. The study aim was to supplement existing outcome information for aortic valve repair.**

*Methods:* **Between 2003 and 2012, a total of 150 consecutive patients (119 males, 31 females; mean age 51.1 years) with significant aortic regurgitation and aortic root enlargement underwent aortic valve repair and associated root reconstruction. The same prospective selection criteria and systematic valve repair approaches were followed throughout the study. Root management consisted of either root remodeling or reimplantation with Dacron prostheses. Kaplan-Meier techniques were used to assess major end-points of all-cause mortality, reoperation, and repair failure. Univariable log-rank testing identified any associations between risk factors and major events.**

*Results:* **The early mortality rate was 2.7% (n = 4), and early repair failure rate 3.3% (n = 5). At a mean follow up of 43.6 months (1st, 3rd percentile, 17.8, 78.0 months), the survival rate was 93% and freedom from reoperation 91%. Univariable risk factors for mortality included advanced preoperative NYHA class and a requirement for root replacement. Repair failure and reoperation were associated with bicuspid valve anatomy, subcommissural annuloplasty, leaflet resection with pericardial patching, and Gore-Tex leaflet reinforcement.**

*Conclusion:* **The present data, acquired from a prospective cohort of patients undergoing aortic valve repair and root reconstruction, reinforced the satisfactory late results obtained with valve reconstruction. These findings also support a broader application of aortic valve repair in future patients.**

The Journal of Heart Valve Disease 2014;23:414-423

Interest in aortic valve repair during aortic root reconstruction is increasing (1), and valve-sparing operations, as introduced by David and colleagues (2,3), Yacoub et al. (4) and Schäfers et al. (5), are being more commonly applied. Leaflet repair techniques, such as central leaflet plication, are becoming standardized (6-9), and have contributed significantly to improving results. Other important developments include a classification of aortic regurgitation (AR) (10,11), echocardiographic standardization (12), and a better understanding of bicuspid valve anatomy (13). Nonetheless, the application of aortic valve repair is lagging, with repair being applied in only 11.3% of aortic root procedures in the Society of Thoracic Surgeons (STS) database over the past decade (1). One potential cause of individual surgeon reluctance could be the still limited amount of long-term data that have been generated - and only in a few centers. Hence, the study aim was to examine a single-center experience with aortic valve repair over 10 years to further clarify the future application of aortic valve repair and root reconstruction.

Presented at the 26th Annual Meeting of the European Association for Cardio-Thoracic Surgery, 29th October 2012, Barcelona, Spain

Address for correspondence:
Marek Jasinski MD, PhD, Medical University of Silesia, 2nd Department of Cardiac Surgery, Ziolowa 47, 40-635 Katowice, Poland
e-mail: marekjas@poczta.onet.pl

## Clinical material and methods

### Patient population

A total of 150 consecutive patients undergoing elective or urgent aortic valve-sparing surgery for chronic AR and/or associated root aneurysm between 2003 and 2012 were enrolled prospectively into the study. Patients undergoing surgery for emergency indications (e.g., acute aortic dissection) were excluded. Preoperative transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) were performed according to a defined protocol. The type of AR was systematically described, patients suitable for repair were identified, and surgical procedures performed according to a consistent approach. Operative characteristics, as well as early postoperative outcomes, were recorded prospectively using a pre-established data set.

Approval to conduct the study was granted by the Ethics Committee of the Medical University of Silesia.

### Echocardiography and patient selection

TTE was performed preoperatively, and repeated one and six months after surgery. Subsequently, TTE was performed at one-year intervals, according to published guidelines (12). A thorough TEE examination was performed after the induction of general anesthesia, before cardiopulmonary bypass (CPB), and then repeated at the end of the surgical procedure. Required echocardiographic views (parasternal long-axis, apical four- and five-chamber) with pre-specified two-dimensional (2D) cine loops were recorded, as well as M-mode and Doppler data.

Patients were selected for aortic valve repair on the basis of their echocardiographic findings, taking into account the magnitude and character of AR, the occurrence and location of leaflet prolapse, the direction of the resulting AR jet, any specific bicuspid anatomy, the pliability/calcification of the leaflets, annular size, sinotubular junction (STJ) dimensions, and aortic diameters. Aortic root dilatation was defined as significant when the sinus diameter was >4.5 cm in bicuspid anatomy, and 5.0 cm in trileaflet anatomy (14).

### Surgical management

All operations were performed through a median sternotomy, with standard CPB and cannulation of the aortic arch, right atrium and superior pulmonary vein. Myocardial protection was accomplished with anterograde cold blood cardioplegia and maintained with direct coronary reinfusion every 20 min. The ascending aorta was opened transversely, 1.5 cm above the tops of the commissures. For valve assessment, three stay sutures of 4/0 Prolene were placed above the highest point of each commissure and positioned under tension. First, the effective height of each leaflet was evaluated (15,16), as well as central leaflet coaptation and individual leaflet prolapse. Second, the relative lengths of the leaflet free margins were assessed with the Frater technique (17); that is, by suturing three noduli of Arantii together and identifying any leaflets with disparately stretched, elongated segments producing prolapse (18-20).

The type of repair was defined by the functional classification of El Khoury et al. (10):

- Type Ia: STJ remodeling was performed with the size of aortic prosthetic graft equal to the ventriculo-aortic junction (VAJ) diameter. The anastomosis between the root and Dacron graft involved equal spacing between commissures.
- Type Ib: Root remodeling was performed with individual sinus replacement. The aortic prosthetic graft size was selected to be equal to the VAJ diameter. The annular diameter should be ≤28 mm.
- Type Ic: Subcommissural annuloplasty was performed with pledgetted 2-0 braided sutures, including the middle third of the subcommissural triangles.
- Type Ia+b+c: Initially, a 'David I' valve reimplantation was employed, with a straight Dacron graft sized 2-4 mm larger that the desired STJ, measured over a 'Freestyle' sizer to produce satisfactory leaflet apposition. Since 2009, a modified reimplantation was employed, with a Valsalva conduit producing a different shape and size of aortic root. The Valsalva conduit diameter was chosen based on the height of the non-left coronary commissure. In reimplantation procedures, 10 to 12 pledgetted 2-0 horizontal mattress sutures formed a proximal suture line at the VAJ, and a second outflow line was created with three running 4-0 Prolene sutures, starting from the nadirs of each neosinus up to the highest commissural fixation.
- Type II: With leaflet prolapse, two techniques were chosen: 7-0 Gore-Tex free-edge stabilization; and leaflet plication. The first technique was begun by suturing the Gore-Tex suture to the aorta at the commissure of the prolapsing leaflet, and then running a locking stitch along the free edge, referencing the length reduction to the normal adjacent leaflet. Leaflet plication relied on free margin length assessment, and excess/prolapsing leaflet tissue was plicated centrally with 7-0 Prolene (17).

J Heart Valve Dis
Vol. 23. No. 4
July 2014

- Bicuspid valve disease: Usually, subcommissural annuloplasty was performed combined with raphe excision and autologous pericardial patch reconstruction. Gore-Tex leaflet stabilization or leaflet plication was added as necessary to correct the prolapse (18), and additional root stabilization was performed with a remodeling straight aortic graft for a sinus diameter >45 mm.

After aortic valve repair, the coaptation height was considered acceptable if it was ≥4 mm. Mild AR (grade 1) was defined by vena contracta of less than 3 mm, central jet with ratio to left ventricular outflow tract (LVOT) width below 25%, and a normal flow pattern in the descending aorta. Moderate residual AR (grade 2) was defined by a vena contracta of 3-6 mm and jet-to-LVOT ratio of between 25% and 65%. These could be accompanied by some degree of diastolic flow reversal in the descending aorta, but with an end-diastolic velocity <20 cm/s. Higher values of the listed parameters indicated severe residual AR (grade 3). Finally, transvalvular gradients were determined with continuous-wave Doppler echocardiography.

**Data acquisition and statistical analysis**

Baseline demographic, clinical and echocardiographic data were recorded prospectively, while operative and follow up data subsequently were collected directly and by reviews of the patients' records. As part of the prospective study, all patients were scheduled for clinical and echocardiographic follow up at one month, six months, one year, and at yearly intervals thereafter. All 150 patients operated on between 2003 and 2012 were identified and included in the study. Follow up data also were confirmed through the National Registry, and 100% completeness was achieved for primary end-point data. For the various events, unadjusted operative mortality (UOM) and seven morbidity-related end-points were evaluated, according to the 2008 STS valve model and STS definitions for morbidity and composite end-points (21).

In order to determine prognostic factors for the development of valve-related events and long-term survival, lists of potential preoperative and perioperative risk factors were developed, including baseline characteristics and different techniques of surgical management. As baseline characteristics, standard STS variables (http://www.sts.org) were included. Candidate covariates then were related to all end-points of the study, including mortality, repair failure and reoperation, using univariable Kaplan-Meier techniques. Multivariable analysis was not possible because of the low event rate; hence, for statistical analyses Kaplan-Meier time-to-event curves were generated, and univariable log rank tests were employed to compare outcomes relative to subgroups. Mann-Whitney Rank Sum Tests were used to evaluate continuous data. A p-value <0.05 was considered to be statistically significant.

All statistical analyses were performed using Sigma Plot 10.0 (Systat Software, Inc., San Jose, CA, USA).

*Table I: Valve and procedural characteristics.*

| Procedure | No. of patients |
|---|---|
| Leaflet repair | |
| Tricuspid valve | 117 (78) |
| Bicuspid valve | 33 (22) |
| Leaflet plication | 23 (15) |
| Gore-Tex reinforcement | 19 (13) |
| Resection/pericardial patch | 20 (13) |
| Leaflet shaving | 10 (7) |
| Annular stabilization | |
| Subcommissural annuloplasty | 79 (53) |
| Remodeling STJ + aorta replacement | 25 (17) |
| Remodeling root + aorta replacement | 18 (12) |
| Root stabilization: remodeling | 43 (29) |
| Reimplantation - overall | 45 (30) |
| Reimplantation (David I) | 21 (14) |
| Reimplantation (Valsalva graft) | 24 (16) |

Values in parentheses are percentages.
STJ: Sinotubular junction.

## Results

**Early outcomes**

Baseline characteristics for the 150 patients undergoing aortic valve repair included: mean age 51.1 ± 17.5 years; male gender (80%); NYHA class III/IV (29%); mean serum creatinine level 1.12 ± 1.5 mg/dl; mean body weight 82.2 ± 9.9 kg; and mean height 175.1 ± 9.9 cm. Comorbidities included smoking (46%), hypertension (63%), hyperlipidemia (36%) and diabetes (43%).

Classification categories included: Type Ia/b (n = 43), Type Ib+Ic (n = 45), Type Ic (n = 79), and Type II (n = 45). The cusp anatomy was trileaflet in 117 patients and bicuspid in 33 (Table I). Leaflet repair consisted of free-edge remodeling with 7/0 Gore-Tex in 19 patients, leaflet plication in 23, and triangular resection with or without patch in 20. Annular stabilization was performed with subcommissural annuloplasty in 79 patients, STJ remodeling was established in 35, and reimplantation into the aortic graft in 45. Root management was performed as reimplantation in 45 and remodeling in 43. Six patients had concomitant CABG, eight had mitral procedures, and three had

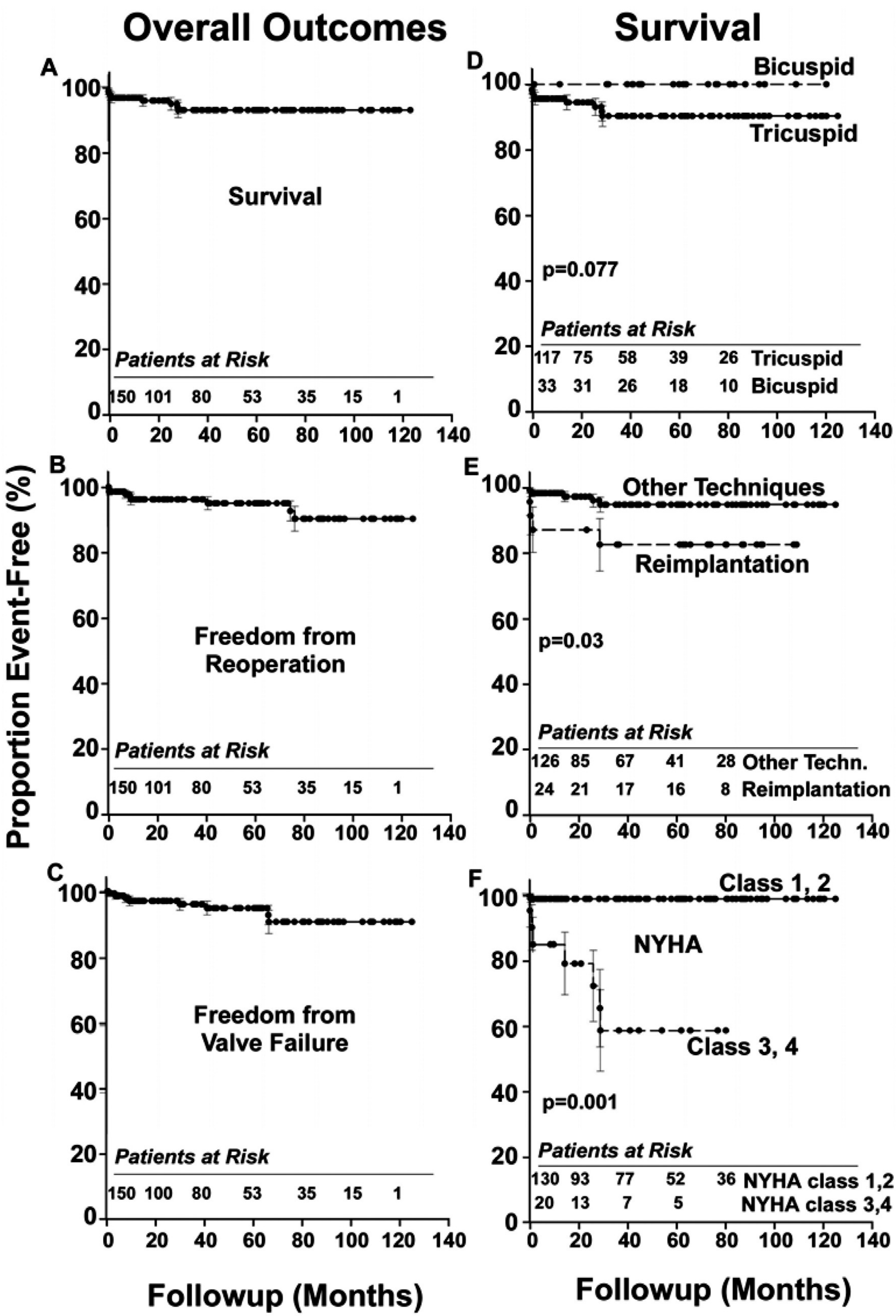


*Figure 1: Overall outcomes with (A) survival, (B) freedom-from-reoperation, and (C) freedom-from-AR grade >2+. D–F) Univariable predictors of survival. Univariable bicuspid survival may be accentuated because of a younger age for bicuspid patients (37.3 ± 15.5 years) than for tricuspid patients (54.9 ± 16.2 years) (p <0.001).*

*Table II: Postoperative outcomes.*

| Parameter | Value | |
|---|---|---|
| | Preoperative | 1 year postoperative |
| Perioperative echo data (n = 150) | | |
| AR type | | |
| Ia/Ib | 43 (29) | - |
| Ib/Ic | 45 (30) | - |
| Ic | 79 (53) | - |
| II | 45 (30) | - |
| Average AR grade: 0-3 (perioperative) | 2.3 | 0.8 |
| AR, none-trivial (n) | 12 | 55 |
| AR, mild (n) | 15 | 70 |
| AR, moderate (n) | 60 | 5 |
| AR, severe (n) | 63 | 0 |
| EDV (ml)* | 221.4 ± 111.2 | 178.9 ± 62.0 |
| EF (%)* | 52.3 ± 11.3 | 52.1 ± 10.1 |
| Operative/Postoperative | | |
| Graft size (mm)* | 25.9 ± 2.6 | |
| Cross-clamp time (min)* | 85.9 ± 41.9 | |
| Temperature on CPB (°C)* | 34.3 ± 4.3 | |
| CPB time (min)* | 123.6 ± 61.7 | |
| Early mortality (n) | 4 (2.7) | |
| Early AVR conversion (n) | 5 (3.3) | |
| Reoperation for bleeding (n) | 6 (4) | |
| IABP (n) | 7 (4.7) | |
| Low cardiac output (n) | 3 (2) | |
| Ventilator >48 h (n) | 6 (4) | |
| Dialysis-dependent renal failure (n) | 2 (1.3) | |
| Deep sternal infection (n) | 1 (0.7) | |

*Values are mean ± SD. Values in parentheses are percentages.
AR: Aortic regurgitation; AVR: Aortic valve repair; CPB: Cardiopulmonary bypass; EDV: End-diastolic volume; EF: Ejection fraction; IABP: Intra-aortic balloon pump.

tricuspid valve surgery. In-hospital mortality was 2.7% (n = 4); the causes were multiorgan failure (n = 2) and congestive heart failure (n = 2).

All operative data are listed in Table II. The mean cardiac ischemic time was 85.9 min, and the CPB time 123.6 min. There were five procedural conversions or reoperations during the same admission (3.3%). These included root remodeling failure in one patient, bicuspid aortic valve (BAV) repair failure in two patients, and trileaflet prolapse (treated with Gore-Tex remodeling) also in two patients. Prosthetic valve replacements were performed in all cases, including two Bentall operations. No deaths occurred in patients undergoing conversion.

The postoperative and echocardiographic outcomes are also listed in Table II. Shortly after repair, the majority of patients had none to mild AR, and only 3% had moderate residual leak. The decrease in end-diastolic volume shortly after valve repair was clinically and statistically significant (p = 0.04).

**Late outcomes**

Five patients died during the follow up period. At a mean follow up of 48.6 ± 34.3 months (median 43.6 months; 1st, 3rd percentile 17, 78 months), the median overall survival was 93.0 ± 1.9% (Fig. 1). One late death occurred after emergency reoperative surgery for type Ib dissection. Five patients developed moderate-to-severe AR. The overall five-year freedom from AR grade >2 was 93.0 ± 3.2%.

Six patients required late reoperation. Two reoperations were not valve-related; these included acute dissection of the aortic arch and descending aorta in one patient, and chronic dissection of the descending aorta in a Marfan patient. Other reoperations were required due to ventricular septal defect at the level of the peri-membranous septum related to rupture of the subcommissural annuloplasty, and BAV complex repair disruption after raphe excision with patching and Gore-Tex stabilization. The mean time to reoperation was 26.6 ± 31.9 months

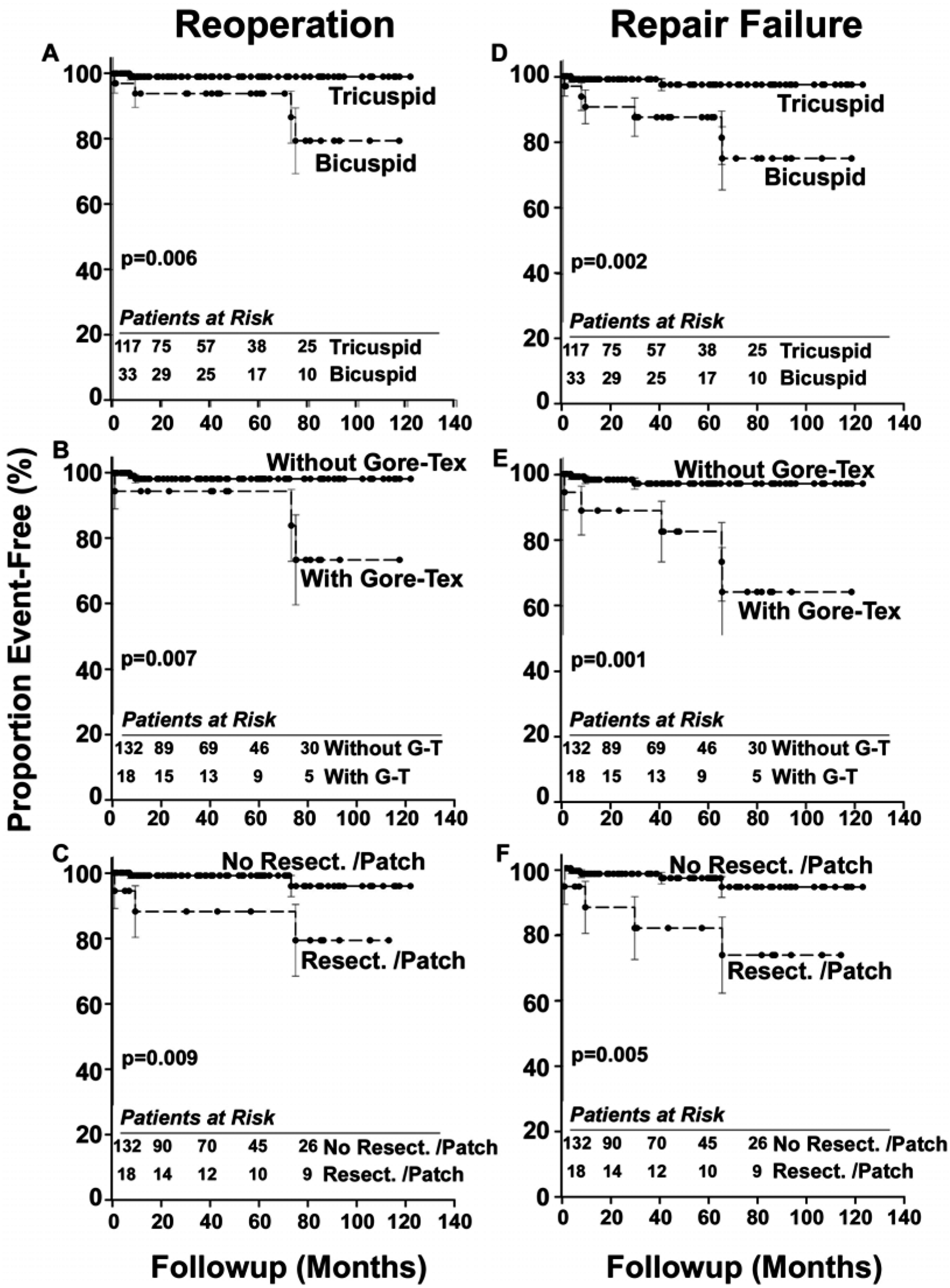


*Figure 2: A-C) Univariable predictors of reoperation. D-F) Univariable predictors of repair failure (AR grade >2+).*

J Heart Valve Dis
Vol. 23. No. 4
July 2014

*Table III: Late events.**

| Variable | Late mortality | | Reoperation | | Valve-related reoperation | | Structural valve deterioration end-point | | Combined | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LRTS | p-value | LRTS | p-value | LRTS | p-value | LRTS | p-value | LRTS | p-value |
| Urgent operation | 0.59 | 0.44 | 1.27 | 0.26 | 0.78 | 0.39 | 1.2 | 0.27 | 0.89 | 0.35 |
| NYHA class ≥III | **35.8** | **<0.001** | 0.04 | 0.85 | 0.54 | 0.46 | 0.88 | 0.35 | **13.4** | **<0.001** |
| Cusp plication | 1.17 | 0.28 | 0.0001 | 0.97 | 0.24 | 0.62 | 1.74 | 0.19 | 0.36 | 0.55 |
| Subcommissural repair | 2.0 | 0.16 | *3.33* | *0.068* | **4.2** | **0.04** | 1.19 | 0.28 | 0.07 | 0.79 |
| Bicuspid valve | *-3.13* | *0.077* | **2.41** | **0.12** | ***7.44*** | ***0.006*** | **9.84** | **0.002** | 0.47 | 0.49 |
| Gore-Tex used | 0.04 | 0.84 | **13.84** | **<0.001** | **7.23** | **0.007** | **14.56** | **<0.001** | **4.98** | **0.03** |
| Resection | 0.7 | 0.4 | **10.02** | **0.002** | **16.92** | **<0.001** | **20.74** | **<0.001** | **5.6** | **0.02** |
| Patch | 0.22 | 0.64 | 0.24 | 0.62 | 0.17 | 0.68 | 2.65 | 0.1 | 0.5 | 0.48 |
| Decalcification | 0.45 | 0.5 | 0.43 | 0.5 | 0.29 | 0.59 | 0.43 | 0.5 | 1.0 | 0.31 |
| Resection and patch | 1.42 | 0.23 | *3.12* | *0.077* | **6.78** | **0.009** | **7.77** | **0.005** | 0.73 | 0.39 |
| STJ-plasty | 0.17 | 0.68 | 0.26 | 0.6 | 1.1 | 0.29 | 0.21 | 0.64 | 0.23 | 0.63 |
| Remodeling STJ | 1.8 | 0.18 | 0.08 | 0.78 | 0.05 | 0.83 | 0.56 | 0.45 | 0.48 | 0.49 |
| Remodeling root | 1.06 | 0.3 | 1.01 | 0.31 | 0.61 | 0.43 | 0.01 | 0.91 | 0.36 | 0.55 |
| Remodeling overall | 0.26 | 0.61 | 0.14 | 0.71 | 0.14 | 0.7 | 0.16 | 0.68 | 0.19 | 0.66 |
| Remodeling root+overall | 0.26 | 0.61 | 0.14 | 0.71 | 0.14 | 0.7 | 0.16 | 0.68 | 0.19 | 0.66 |
| Reimplantation 1 | **4.71** | **0.03** | 1.85 | 0.17 | 1.21 | 0.27 | 2.0 | 0.15 | 0.1 | 0.75 |
| Reimplantation overall | *3.19* | *0.074* | 0.4 | 0.53 | 1.49 | 0.22 | 2.4 | 0.12 | 0.29 | 0.58 |
| Reimplantation (Valsalva) | 1.23 | 0.27 | 1.02 | 0.31 | 2.04 | 0.15 | *-3.29* | *0.07* | 0.04 | 0.84 |
| Root replacement (root remodeling + reimplantation | **5.05** | **0.025** | 1.52 | 0.22 | 2.55 | 0.11 | 1.69 | 0.19 | 0.78 | 0.38 |
| MV/TV/CABG | 0.86 | 0.35 | 0.02 | 0.89 | 0.44 | 0.51 | 0.96 | 0.33 | 0.32 | 0.57 |

*Significant effects shown by univariable analysis are marked in bold text; trends are marked in italic text.
CABG: Coronary artery bypass graft; LRTS: Log-rank test statistic; MV: Mitral valve; STJ: Sinotubular junction; TV: Tricuspid valve.

(median 9 months; 1st, 3rd percentile, 2, 64 months), and the time to valve-related reoperation 47.6 ± 34.5 months (median 9 months; 1st, 3rd percentile, 4, 71 months). The overall six-year freedom from reoperation was 91.4%.

**Risk factor analysis**

In the long-term analysis, no patients were lost to follow up. Significant univariable risk factors (Table III; Fig. 2) included: long-term mortality (NYHA class, creatinine level, low ejection fraction (EF), and root replacement with valve reimplantation); reoperation (leaflet resection with patching, and use of Gore-Tex for free-edge remodeling); valve-related reoperation (BAV, subcommissural annuloplasty, leaflet resection with patching, and use of Gore-Tex for free edge remodeling); AR recurrence (BAV, Gore-Tex leaflet edge remodeling, and leaflet resection with patching).

## Discussion

The primary reason for transitioning to aortic valve repair is a lower incidence of long-term valve-related complications (22,23), as compared to prosthetic valve replacement (24,25). However, aortic valve sparing currently is being applied to only a minority of overall patients, despite equivalent or lower operative mortality across the spectrum of patient risk, as compared to composite valve replacement (26). Thus, in the STS database since 2000, only 11.3% of aortic root replacements have involved aortic valve repair (1). One possible reason for such a slow adoption is the lack of a widely accepted systematic approach allowing for clearly reproducible results. In the current 10-year experience, El Khoury's surgical algorithm was applied consistently, and all patients were followed with defined protocols. In an effort to better understand the subject, the type of AR was classified (10) and used to apply validated surgical techniques (11). In this single-center prospective study, the feasibility of aortic valve repair with associated aortic root management was demonstrated, and the approach provided satisfactory long-term survival, freedom from reoperation, and valve repair stability.

A second reason for such slow adoption may be the limited outcome data currently available to support valve reconstruction. Several centers recently have examined the detailed results of aortic repair (27-32), and the present findings reinforce most of their conclusions. Over an eight-year follow up, the Brussels group (10) found an overall survival of 87%, freedom from reoperation of 91%, and freedom from recurrent AR of 79%. The series from Homburg-Saar showed similar results, for both trileaflet and bicuspid valves (21). The results of the present study correlated well with both of these experiences, in that the majority of patients had none to mild AR early after repair (Table II), and a minority had moderate residual leak. At follow up, these results were stable and largely sustained in the long term, with acceptable rates of survival, reoperation, and recurrent AR (Figs. 1 and 2). Repair efficacy also was illustrated by the decreasing EDV and improving EF - findings that are indicative of ventricular recovery from volume overload.

An important risk factor for both early and late mortality was advanced preoperative heart failure. This finding may reflect the heterogeneous population in the present series, with a significant proportion of urgent, higher-risk patients. Given the prospective nature of the study design, patients were pre-selected only on the basis of echocardiographic analysis, and urgent patients with severe congestive heart failure symptoms were included in the repair group. The results of one recent study suggested that aortic valve sparing can be performed with no higher mortality in high-risk than in low-risk patients, and the present experience would support that concept (26).

Techniques of leaflet repair are still evolving, and the present findings support those of previous studies which showed the high efficacy of central leaflet plication for correction of prolapse. Conversely, Gore-Tex free margin reinforcement did not fare well, although in the present analysis this variable could be a surrogate for worse baseline leaflet disease. Certainly, a technique would be preferred that was successful enough to neutralize the prognostic effects of leaflet disease, and it appears that Gore-Tex leaflet reinforcement does not do this. Commissural suspension or the Trusler stitch for correction of prolapse also probably should be avoided, because of late disruption at the high-stress regions of commissural leaflets (33). Thus, at present leaflet plication probably should be the first choice for prolapse correction, and in fact the availability and validation of this technique is a major enabler for the expansion of aortic valve reconstruction.

Aortic root reimplantation with the David I procedure (straight aortic graft) was found to be a negative prognostic factor in the present experience, though it was strictly limited to the early postoperative period. This finding may be related to the higher complexity of this operation and the longer cross-clamp and CPB times required, both of which were predictors of early mortality. A concept also exists that severe valve pathology portends a less good result with reimplantation (34), although this is controversial. Interestingly, however, no late events were observed after a successful David procedure in this series, confirming its durability (Table III). David and Feindel (2) found 95% freedom from severe valve dysfunction at 10 years, while Shrestha et al. (28) described an 85% freedom from reoperation. The present results confirmed few late cardiac-related events after a reimplantation-type aortic valve-sparing operation, although complexity and poorer applicability in severe valve dysfunction may be problematic.

The strongest predictor for recurrent AR in the present series was BAV. Boodhwani and associates (35) found similar long-term results between bicuspid and trileaflet aortic valve repair, while Aicher et al. (36) and Casselman et al. (37) confirmed adequate stability after BAV repair, though with a higher late failure rate. Boodhwani et al. (35) also described perioperative factors that negatively influenced bicuspid repair durability, such as raphe resection and pericardial patches during leaflet repair, thereby confirming the data of earlier studies. It is possible that, in some settings, severe leaflet disease might be better treated with complete leaflet replacement with glutaraldehyde-fixed autologous pericardium (38), as currently being evaluated by Ozaki et al. (39). Similarly, annuloplasty techniques are currently in-flux, and suture-based subcommissural annuloplasty can fail, due to late re-dilation of the aortic root. Root stabilization with reimplantation has provided better stability than subcommissural annuloplasty (35), but Schaefers and colleagues (5) have also shown excellent stability with root remodeling combined with subcommissural or circular suture annuloplasty. Each of these findings correlates with those of the present study. The development of annuloplasty rings for the aortic valve may also prove useful (40).

*In conclusion*, data acquired from the long-term follow up of a prospectively analyzed cohort of patients suggested that aortic valve repair and associated aortic root reconstruction can be performed with satisfactory results and good late durability. However, the results could be further improved with a more aggressive root stabilization, especially during BAV repair. Advances in leaflet techniques and a more liberal use of leaflet plication could also be helpful. Further efforts to develop repair methods, as well as a greater application of aortic valve reconstruction, seem indicated.

**Acknowledgements**

Dr. Rankin is Chief Medical Officer of BioStable Science and Engineering, Inc.

**References**

1. Caceres M, Ma Y, Rankin JS, et al. The evolving practice of aortic root surgery in North America. Ann Thorac Surg 2014 (in press)
2. David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. J Thorac Cardiovasc Surg 1992;103:617-622
3. David TE, Feindel CM, Webb GD, et al. Aortic valve preservation in patients with aortic root aneurysm: Results of the reimplantation technique. Ann Thorac Surg 2007;83:S732-S735
4. Yacoub MH, Gehle P., Chandrasekaran V, et al. Late results of a valve-sparing operation in patients with aneurysm of aorta and root. J Thorac Cardiovasc Surg 1998:115:1080-1090
5. Schäfers H-J, Kunihara T, Fries P, et al. Valve-preserving root replacement in bicuspid aortic valves. J Thorac Cardiovasc Surg 2010;140:S36-S40
6. Schäfers H-J. Reconstruction of the bicuspid aortic valve. Op Tech Thorac Cardiovasc Surg 2007;12: 2-13
7. Aicher D, Langer F, Adam O, et al. Cusp repair in aortic valve reconstruction: Does the technique affect stability? J Thorac Cardiovasc Surg 2007;134:1533-1539
8. Chiappini B, Pouleur A-C, Noirhomme P, et al. Repair of trileaflet aortic valve prolapse: Mid-term outcome in patients with normal aortic root morphology. Interact CardioVasc Thorac Surg 2007;6:56-59
9. Price J, De Kerchove L, El. Khoury G. Aortic valve repair for leaflet prolapse. Semin Thorac Cardiovasc Surg 2011;23:149-151
10. El. Khoury G, Glineur D, Rubay J, et al. Functional classification of aortic root/valve abnormalities and their correlation with etiologies and surgical procedures. Curr Opin Cardiol 2005;20:115-121
11. Boodhwani M, De Kerchove L, Glineur D, et al. Repair-orientated classification of aortic insufficiency: Impact on surgical techniques and clinical outcomes. J Thorac Cardiovasc Surg 2009;137:286-294
12. The Joint Task Force on the management of Valvular Heart Disease of the ESC and EACTS. Guidelines on the management of Valvular Heart Disease. Eur J Cardiothorac Surg 2012;42:S1-S44
13. Sievers HH, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. J Thorac Cardiovasc Surg 2007;133:1226-1233
14. 2006 Writing committee members, 2008 focused update incorporated into the ACC/AHA 2006 Guidelines for the Management of Patients with Valvular Heart Disease. Circulation 2008;118: e523-e661
15. Schäfers H-J, Bierbach B, Aicher D. A new approach to the assessment of aortic cusp geometry. J Thorac Cardiovasc Surg 2006;132:436-438

16. Aicher D, Langer F, Adam O, et al. Bicuspid valve repair. Circulation 2011:123;178-185
17. Kirklin JW, Barratt-Boyes BG. Ventricular septal defect and aortic incompetence. In: Kirklin JW, Barratt-Boyes BG (ed.), Cardiac Surgery. John Wiley & Sons, New York, 1986:657
18. De Kerchove L, Boodhwani M, Glineur D, et al. Cusp prolapse repair in trileaflet aortic valves: Free margin plication and free margin resuspension techniques. Ann Thorac Surg 2009;88:455-461
19. De Kerchove L, Glineur D, Poncelet A, et al. Repair of aortic leaflet prolapse, a ten year experience. Eur J Cardiothorac Surg 2008;34:780-784
20. Boodhwani M, De Kerchove L, Glineur D, et al. Assessment and repair of aortic valve cusp prolapse: Implications for valve-sparing procedures. J. Thorac Cardiovasc Surg 2011;141:917-925
21. O'Brien SM, Shahian DM, Filardo G, et al. The STS 2008 cardiac surgery risk score models: Part 2 isolated valve surgery. Ann Thorac Surg 2009;88: 23-42
22. Aicher D, Fries R, Rodionycheva S, et al. Aortic valve repair leads to a low incidence of valve-related complications. Eur J Cardiothorac Surg 2010;37:127-132
23. Price J, De Kerchove L, Glineur D, et al. Risk of valve-related events after aortic valve repair. Ann Thorac Surg 2013;95:606-613
24. Hammermeister K, Sethi GK, Henderson WH, et al. Outcomes 15 years after valve replacement with a mechanical versus a bioprosthetic valve: Final report of the Veterans Affairs randomized trial. J Am Coll Cardiol 2000;36:1152-1158
25. Brennan JM, Edwards FH, Zhao Y, et al. Long-term safety and effectiveness of mechanical versus biologic aortic valve prostheses in older patients: Results from the Society of Thoracic Surgeons adult cardiac surgery national database. Circulation 2013;127:1647-1655
26. Caceres M, Ma Y, Rankin JS, et al. Mortality characteristics of aortic root surgery in North America. Eur J Cardiothorac Surg 2014;doi: 10.1093/ejcts/ezu083
27. Badiu C, Bleiziffer S, Eichinger W, et al. Are bicuspid aortic valves a limitation for aortic valve repair? Eur J Cardiothorac Surg 2011;40:1097-1104
28. Shrestha M, Pichlmaier M, Baraki H, et al. Long term results after aortic valve-sparing operation. Eur J Cardiothorac Surg 2012;41:56-62
29. Leontyev S, Trommer C., Subramanian S, et al. The outcome after aortic valve-sparing (David) operation in 179 patients: A single- center experience. Eur J Cardiothorac Surg 2012;42: 261-267
30. Cameron DE, Alejo DE, Patel ND, et al. Aortic root replacement in 372 Marfan patients: Evolution of operative repair over 30 years. Ann Thorac Surg 2009;87:1344-1350
31. Kvitting JE, Kari FA, Fischbein MP, et al. David valve-sparing aortic root replacement: Equivalent mid-term outcome for different valve types with or without connective tissue disorder. J Thorac Cardiovasc Surg 2013;145:117-127
32. Urbanski P, Zhan X, Hijazi H, et al. Valve-sparing aortic root repair without down-sizing of the annulus. J Thorac Cardiovasc Surg 2012;143:294-302
33. Marom G, Haj-Ali R, Raanani E, et al. A fluid-structure interaction model of the aortic valve with coaptation and compliant aortic root. Med Biol Eng Comput 2012;50:173-182
34. David TE. Surgical treatment of aortic valve disease. Nat Rev Cardiol 2013;10:375-386
35. Boodhwani M, de Kerchove L, Glineaur D, et al. Repair of regurgitant bicuspid aortic valves: A systematic approach. J Thorac Cardiovasc Surg 2010;140:276-284
36. Aicher D, Kunihara T, Issa OA, et al. Valve configuration determines long-term results after repair of the bicuspid aortic valve. Circulation 2011;123:178-185
37. Casselman FP, Gillinov AM, Akhrass R, et al. Intermediate-term durability of bicuspid aortic valve repair for prolapsing leaflet. Eur J Cardiothorac Surg 1999;15:302-308
38. Rankin JS, Crooke PS, Lange R, Mazzitelli D. Techniques of autologous pericardial leaflet replacement for bicuspid aortic valve endocarditis. J Heart Valve Dis 2013;22:724-731
39. Ozaki S, Kawase I, Yamashita H, et al. A total of 404 cases of aortic valve reconstruction with glutaraldehyde-treated autologous pericardium. J Thorac Cardiovasc Surg 2014;147:301-306
40. Mazzitelli D, Stamm C, Rankin JS, et al. Hemodynamic outcomes of geometric ring annuloplasty for aortic valve repair: A four-center pilot trial. J Thorac Cardiovasc Surg 2014;148: 168-175