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The Bicuspid Aortic Valve Repair With External Or Subcommissural Annuloplasty – A 13-Year Experience

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Abstract: Background and Aim of the Study: An incompetent bicuspid aortic valve (BAV) can be treated through valve replacement or repair using various surgical techniques. This study presents the outcomes of a 13-year single-surgeon experience in BAV repair and compares two annuloplasty techniques: external and subcommissural aortic annuloplasty. **Materials and Methods:** A total of 150 consecutive patients (111 males; mean age: 43.2 ± 17.5 years) with BAV insufficiency, with or without aortic dilatation, underwent valve repair at three institutions. Multivariable logistic regression was used to identify associations between risk factors and major adverse events. Among these, 50 patients were prospectively assigned to one of two groups based on the annular stabilization technique: Group EA received external annuloplasty, while Group SCA underwent subcommissural annuloplasty. All patients in both groups were evaluated by transthoracic echocardiography before surgery and two years postoperatively. **Results:** There was no in-hospital mortality, and all patients survived throughout the follow-up period. Nine patients (6%) developed moderate to severe postoperative insufficiency and required reoperation. The Kaplan–Meier estimated freedom from reoperation at eight years was 100% in patients who did not undergo subcommissural annuloplasty, compared to 81% in those who did ($p = 0.037$). External annuloplasty was associated with a significantly smaller postoperative aortic annulus diameter (24.1 ± 2.6 mm vs. 25.8 ± 2.1 mm, $p < 0.05$), and lower mean and peak transvalvular gradients (7 ± 4 mmHg vs. 13 ± 4 mmHg, $p = 0.02$; and 15.3 ± 9.7 mmHg vs. 20.7 ± 5.6 mmHg, $p = 0.03$, respectively). Aortic root or ascending aorta replacement was also found to be a predictor of repair durability ($p = 0.0039$). **Conclusions:** Bicuspid aortic valve repair provides favorable short- and midterm outcomes. External annuloplasty offers superior annular stabilization and hemodynamic performance compared to subcommissural annuloplasty. Additionally, concomitant aortic replacement further improves the long-term durability of the repair.

Keywords: Aortic Valve Repair, Bicuspid Aortic Valve, Surgical Outcome Analysis, External Annuloplasty, Valve-Sparing Surgery

1. Introduction

A bicuspid aortic valve (BAV) is the most common congenital cardiac abnormality, affecting approximately 1–2% of the general population. Significant aortic insufficiency is more frequently observed in BAV than in tricuspid aortic valves and is often accompanied by aortopathy. In selected patients, BAV can be treated with valve repair rather than replacement [1]. Various surgical techniques for aortic valve repair have been developed [2–5], typically selected based on a surgery-oriented classification of aortic regurgitation (AR) [6,7]. Among the critical factors influencing the durability of valve repair is annular stabilization. However, there is no clear consensus regarding which annuloplasty technique provides the most favorable short- and long-term outcomes in patients with BAV.

This study presents a 13-year single-surgeon experience in BAV repair and provides a comparative analysis of different annular stabilization techniques.

2. Materials and methods

2.1. Patient Population

A total of 150 patients with bicuspid aortic valves (mean age: 43.2 ± 17.5 years; 111 males, 74%) were operated on by a single surgical team led by Professor Marek Jasinski across three centers between 2003 and 2016. All patients underwent elective aortic valve-sparing surgery for chronic aortic regurgitation (AR), with or without concomitant aortic root dilatation. A schematic overview of the study design is presented in Figure 1.

Aortic regurgitation was classified according to established criteria [7], with the following distribution: type Ia/b (dilated ascending aorta and/or root with a normal aortic annulus) in 78 patients (52%), type Ib + Ic (dilated aortic root, ascending aorta, and aortic annulus) in 31 patients (21%), type Ic only (dilated annulus) in 28 patients (19%), and type II (cusp prolapse)

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in 120 patients (80%). Regarding BAV morphology, type 0 was identified in 25 patients (17%), type I in 117 patients (78%), and type II (predominantly unicuspid) in 8 patients (5%).

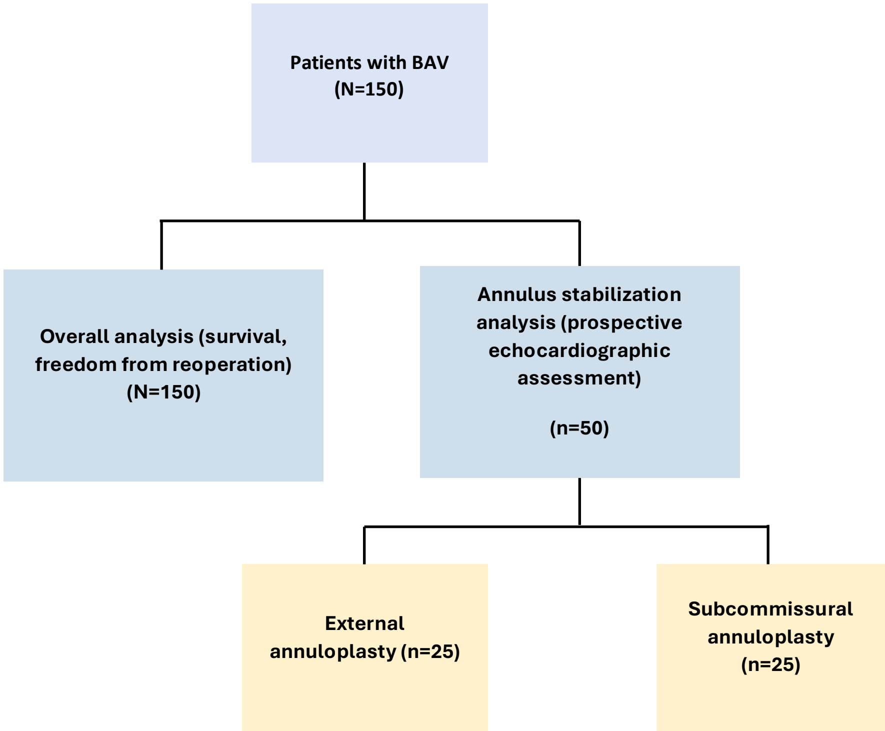

Figure 1: The schematic presentation of the study.

2.2. Echocardiography

Postoperative mortality, morbidity (defined as the need for reoperation), and pre- and postoperative echocardiographic parameters were evaluated. Transthoracic echocardiography (TTE) was performed preoperatively and one month after surgery. Intraoperative transesophageal echocardiography (TEE) was carried out after induction of general anesthesia, both prior to and following cardiopulmonary bypass.

The echocardiographic assessments focused on the degree and nature of AR, the presence and location of leaflet prolapse, specific BAV anatomical features, leaflet and raphe pliability or calcification, annular dimensions, and left ventricular measurements.

2.3. Subanalysis: Aortic Annulus Stabilization

Among the 150 patients, a subgroup of 50 consecutive individuals operated on between 2013 and 2014 was prospectively allocated into two groups based on the aortic annulus stabilization technique used. The first group (EA, mean age: 50.9 years; NYHA class III–IV: 2 patients, 4%) underwent external annuloplasty using a Dacron strip. The second group (SCA, mean age: 50.8 years; NYHA class III–IV: 2 patients, 4%) received subcommissural annuloplasty with pledgeted mattress sutures. Eligibility criteria included BAV type I anatomy with fused leaflets (Sievers classification [13]), moderate to severe AR, an enlarged aortic annulus (>25 mm), and dilatation of the aortic root or ascending aorta. The two groups were comparable in baseline characteristics, including age, ventricular dimensions, aortic measurements, and left ventricular contractility.

All patients in both groups underwent replacement of the ascending aorta. In the EA group, 19 patients had STJ remodeling with ascending aorta replacement, and six underwent valve reimplantation (David procedure). In the SCA group, 21 patients had STJ remodeling and ascending aorta replacement, while four underwent aortic root remodeling.

Echocardiographic evaluations were conducted preoperatively and two years postoperatively, assessing parameters such as mean and peak transaortic gradients, end-diastolic volume and dimension of the left ventricle, and dimensions of the aortic annulus, root, STJ, and ascending aorta. The mean follow-up duration was 594 ± 107.9 days, with group EA at 598 ± 130 days and group SCA at 545 ± 58 days.

2.4. Surgical Management

All surgeries were performed via median sternotomy, utilizing standard cardiopulmonary bypass with cannulation of the ascending aorta or aortic arch and the right atrium. A left ventricular vent was inserted through the right superior pulmonary vein. Myocardial protection was achieved using antegrade cold blood cardioplegia. The ascending aorta was transected above the STJ. Valve assessment included placement of 4/0 Prolene stay sutures above each commissure under tension to facilitate inspection.

The effective height of each cusp, central leaflet coaptation, and leaflet prolapse were evaluated [8,9], followed by assessment of leaflet free margin lengths by approximating the Noduli Arantii to identify prolapsing segments [10–13]. Fused leaflet anatomy was also examined. The aortic regurgitation classification developed by El-Khoury was applied [14]. In type Ia regurgitation, STJ remodeling was performed via ascending aorta replacement. In type Ib, root remodeling involved individual sinus replacement. In type Ic, subcommissural or external annuloplasty, with or without valve reimplantation, was performed. Graft sizing was guided by leaflet height and subcommissural triangle dimensions, using the El-Khoury and David-Feindel formulas [10,15]. Commissures were placed at 180° angles during root remodeling or reimplantation to optimize valve symmetry and leaflet mobility.

Procedure selection and the extent of aortic replacement were guided by the functional classification of AR and the dimensions of the affected aortic segments. The David procedure was reserved for patients with symmetric aortic root enlargement (>45 mm) and annular dilatation.

Annular stabilization was achieved via subcommissural or external annuloplasty. Subcommissural annuloplasty employed two pledgeted braided 2-0 sutures to constrict the subcommissural triangles. External annuloplasty involved interrupted pledgeted 2-0 braided sutures supported by an external Dacron ring, or was performed as part of valve reimplantation. Annuloplasty techniques were supplemented by cusp prolapse repair, raphe excision, and, if necessary, autologous pericardial patch reconstruction. Gore-Tex leaflet resuspension or free margin plication was used to correct leaflet prolapse when required [11].

The TEE assessment during surgery ensured that coaptation height was ≥4 mm following repair. Mild AR (grade 1) was defined by a vena contracta <3 mm, a central jet/LVOT width ratio <25%, and normal descending aortic flow. Moderate AR (grade 2) involved a vena contracta of 3–6 mm and a jet/LVOT ratio between 25–65%, often with mild diastolic flow reversal and end-diastolic velocity <20 cm/sec. Severe AR (grade 3) was defined by higher values. Transvalvular gradients were measured using continuous-wave Doppler.

2.5. Data Acquisition and Analysis

Baseline demographic, clinical, and echocardiographic data were retrospectively collected for the entire cohort, with prospective data collection for the 50 patients in the annulus stabilization subanalysis (EA and SCA groups). Operative and follow-up information was obtained through direct evaluation and review of medical records. Patients in the subanalysis were scheduled for detailed clinical and echocardiographic follow-up at 1,5 years years, which concluded at the end of 2016.

Preoperative and perioperative risk factors, including baseline characteristics and surgical techniques, were examined to identify predictors of valve-related events and long-term survival. This analysis covered the entire cohort of 150 patients. Baseline variables followed the Society of Thoracic Surgeons guidelines [22] and were expressed as means with standard deviations.

Kaplan-Meier analysis was used to estimate actuarial freedom from reoperation over an eight-year period, chosen because at least 15% of the initial cohort remained uncensored at that time point. Group comparisons were performed using the unpaired Student's t-test or the Mann-Whitney U-test for continuous variables and the Chi-square test for categorical data. Associations between potential covariates and study endpoints were analyzed using multivariate logistic regression. Kaplan-Meier survival curves and the log-rank test were used to compare reoperation-free survival between EA and SCA groups. A p-value <0.05 was considered statistically significant. All analyses were conducted using Statistica 12 (Stat-Soft, USA). The study was approved by the Local Ethics Committee under the KNW2/136/06 statutory grant.

3. Results

3.1. Early Outcomes

No patient died during the early postoperative period. Concomitant surgical procedures included coronary artery bypass grafting in six patients (4%), mitral valve procedures in eight patients (5%), and tricuspid valve surgery in three patients (2%). The operative techniques are detailed in Table 1. The mean cardiac ischemic time was 72.4 ± 41.9 minutes, while the mean cardiopulmonary bypass time was 99.4 ± 61.7 minutes.

Table 1: BAV repair techniques (N=150). AR- Aortic regurgitation class, STJ – sino-tubular junction, BAV-bicuspid aortic valve

Surgical techniques used for BAV repair	Number of patients (N=150)
Leaflet plication	103 (69%)
Gore-Tex reinforcement	17 (11%)
Resection/pericardial patch	41 (27%)/8 (5%)
Leaflet shaving	53 (35%)
External annular stabilization	68 (45%)
Subcommissural annuloplasty	64 (43%)
Remodeling STJ+ aorta replacement	47 (31%)
Remodeling root+ aorta replacement	31 (21%)
Reimplantation-Overall	31 (21%)
Reimplantation -Valsalva graft	20 (13%)
Reimplantation -David 1 procedure	11 (7%)

Source: by the author

Three patients (2%) required procedural conversions or reoperations during the same hospital admission. These included one case of failed root remodeling and two cases of unicuspid valve repair failure. All three patients underwent prosthetic valve replacement, with two receiving a Bentall procedure. Postoperative complications are summarized in Table 2.

Table 2: The early postoperative outcomes of patients with bicuspid aortic valve repair (N=150). *IABP – intra-aortic balloon pump*

Early postoperative complications	Number of patients (N=150)
Early mortality	0
Early conversion to aortic valve replacement (intraoperative or on the same admission)	3 (2%)
Reoperation for bleeding	3 (2%)
IABP	2 (1%)
Low cardiac output	3 (2%)
Ventilator>48h	1(1%)
Dialysis dependent renal failure	1 (1%)
Deep sternal wound infection	1 (1%)

Source: by the author

In the early postoperative period, most patients exhibited either no or only mild aortic regurgitation. Moderate residual AR was observed in seven patients (4.6%). The preoperative and six-month postoperative echocardiographic data for the full cohort of 150 patients are presented in Table 3.

Table 3. The preoperative and early (1 month) postoperative echocardiography of all study participants with bicuspid aortic valve repair (N=150), *AR – aortic regurgitation, EF- left ventricle ejection fraction, VAJ – ventriculo-aortic junction, EDV – enddiastolic volume of the left ventricle, EDD – enddiastolic dimension of the left ventricle, ESV – endsystolic volume of the left ventricle*

	Before the operation	After the operation	P value
EF[%]	54.1±7.3	55.4±9.9	0.215
Aortic annulus (VAJ) [mm]	27.1±3.5	25.2±3.3	0.003
Aortic root dimension [mm]	43.6±7.9	38.1±4.4	<0.001
Sino-tubular junction [mm]	36.6±7.6	29.8±3.9	0.002
Tubular ascending aorta dimension [mm]	46.4±9.0	33.4±4.4	<0.001
EDV[ml]	202.36±76.6	159.1±47.4	0.003
EDD [mm]	62.8±9.8	54.5±47.4	0.03
ESV [ml]	110.7±57.9	60.7±41.2	0.009
Mean transaortic gradient [mmHg]	15.3±5.1	12.3±3.05	0.07
Aortic regurgitation width [mm]	10.3±3.5	3.5±2,2	<0.001
AR, none-trivial	8 (5%)	123 (82%)	-
AR, mild	15 (10%)	15 (10%)	-
AR, moderate	63 (42%)	7 (5%)	-
AR, severe	64 (43%)	2 (1%)	-

Source: by the author

3.2. Late Outcomes

All patients survived throughout the follow-up period. The Kaplan-Meier estimated freedom from reoperation was 88% at eight years (Figure 2), and the overall rate at 12.5 years was 83%. Eleven patients (7%) developed moderate-to-severe AR, and nine of these (6%) ultimately required late reoperation.

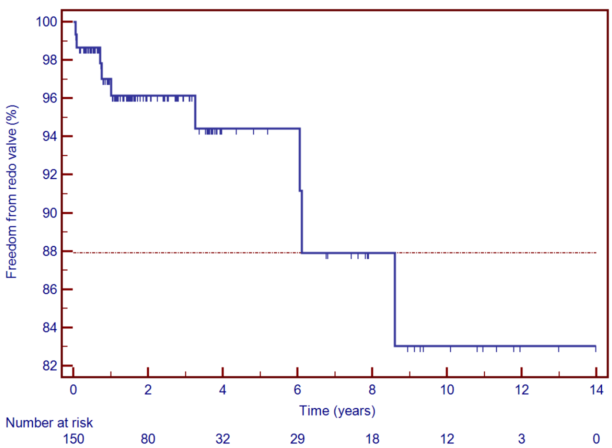

Figure 2: Kaplan-Meier freedom from reoperation for patients undergoing bicuspid aortic valve repair, n=150.

Indications for late reoperation included a ventricular septal defect (VSD) caused by rupture of the subcommissural annuloplasty at the perimembranous septum, failure following subcommissural annuloplasty and raphe excision with Gore-Tex leaflet stabilization (four cases), failure of unicuspid repair (one case), perforation of the non-coronary cusp after subcommissural annuloplasty and patch repair (one case), aortic stenosis following valve repair with concurrent reimplantation (one case), and progression after subcommissural repair with concomitant closure of the ductus arteriosus (one case).

Multivariate logistic regression identified three statistically significant risk factors for reoperation: use of subcommissural annuloplasty (OR: 10.0; 95% CI: 1.5–67.4; $p = 0.0174$), absence of leaflet plication (OR: 8.6; 95% CI: 1.5–48.5; $p = 0.0143$), and the lack of concomitant valve-sparing aortic replacement (OR: 19.8; 95% CI: 2.6–150.8; $p = 0.0039$).

At eight years, the Kaplan-Meier estimated freedom from reoperation was 100% in patients who did not receive subcommissural annuloplasty (n = 87), compared to 81% in those who did (n = 67), as shown in Figure 3.

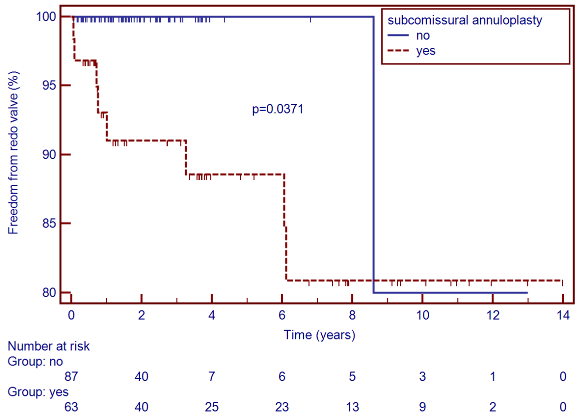

Figure 3: Kaplan-Meier freedom from reoperation for patients with or without subcommissural annuloplasty, n=150.

3.3. Aortic Annulus Stabilization Subanalysis

Patients in the external annuloplasty (EA) and subcommissural annuloplasty (SCA) groups were generally comparable in terms of preoperative echocardiographic parameters (see Table 4). However, significant differences were noted in the maximum aortic root diameter (47.1 ± 4.2 mm in EA vs. 41.1 ± 4.7 mm in SCA, $p = 0.02$), end-systolic volume of the left ventricle (71.2 ± 33.0 ml in EA vs. 112.3 ± 49.4 ml in SCA, $p = 0.04$), and end-systolic dimension of the left ventricle (49.0 ± 8.3 mm in EA vs. 35.7 ± 6.6 mm in SCA, $p < 0.05$).

Postoperative reverse remodeling, as assessed by end-diastolic volume and dimension, was similar between the two groups. Aortic regurgitation, measured by regurgitant jet width, was significantly reduced in both groups after surgery and remained comparable during follow-up. However, a significant reduction in aortic annular diameter was observed only in the EA group (27.5 ± 3.0 mm preoperatively vs. 24.1 ± 2.6 mm postoperatively, $p = 0.002$), whereas the reduction in the SCA group was not statistically significant (27.7 ± 4.7 mm vs. 25.8 ± 3.8 mm, $p = 0.7$).

At 1,5 years follow-up, the EA group exhibited significantly lower mean transvalvular gradients compared to the SCA group (7 ± 4.0 mmHg vs. 12.6 ± 4.6 mmHg, $p = 0.018$). Complete pre- and postoperative echocardiographic data are provided in Table 4.

Table 4. The pre- and postoperative echocardiographic outcomes after bicuspid aortic valve repair from the subanalysis comparing patients with external (group EA, n=25) and subcommissural (group SCA, n=25) annuloplasty. *VAJ-ventriculo-aortic junction, LV- left ventricle*

	Before: (SD)	**F-up: (SD)**	
Aortic Annulus (VAJ) [mm]			
- External annuloplasty (group EA)	27.5(3.1)	24.1(2.6)	**p=0.002**
- Subcommissural annuloplasty (group SCA)	27.7(4.7)	25.8(2.1)	p= 0.7
p level	p=0.9	**p=0.014**	
Aortic Root dimension [mm]			
- External annuloplasty (group EA)	47.1 (4.16)	38.4 (4.6)	**p=0.003**
- Subcommissural annuloplasty (group SCA)	41.1 (4.7)	36.4(3.3)	**p=0.02**
p level	**p=0.02**	p=0.4	
Sino-Tubular Junction dimension [mm]			
- External annuloplasty (group EA)	40.4(4.1)	29.9(3.8)	**p=0.009**
- Subcommissural annuloplasty (group SCA)	40.4 (7.5)	28.6(3.5)	**p=0.02**
p level	p=0.7	p=0.4	
Aorta dimension [mm]			
- External annuloplasty (group EA)	49.5(6.6)	31.5(3.0)	**p<0.001**
- Subcommissural annuloplasty (group SCA)	46.7(8.1)	31.8(3.8)	**p<0.001**
p level	p=0.2	p=0.8	
Enddiastolic volume of the LV [ml]			
- External annuloplasty (group EA)	180.9(52.1)	157.1(40.1)	p=0.06
- Subcommissural annuloplasty (group SCA)	203.7(100.1)	157.1(36.6)	p=0.09
p level	p=0.5	p=0.99	

	Before: (SD)	F-up: (SD)	
Enddiastolic Diameter of the LV [mm]			
- External annuloplasty (group EA)	55.2(5.7)	53.8 (5.3)	p=0.12
- Subcommissural annuloplasty (group SCA)	64.5(10.8)	53.9(7.2)	p=0.06
p level	p=0.1	p=0.8	
Endsystolic Volume of the LV [ml]			
- External annuloplasty (group EA)	71.2(33.0)	69.5(31.4)	p=0.24
- Subcommissural annuloplasty (group SCA)	112.3(49.4)	62.8(24.2)	**p<0.001**
p level	**p=0.04**	p=0.5	
Endsystolic Diameter of the LV [mm]			
- External annuloplasty (group EA)	49.0(8.3)	34.5(3.9)	p=0.3
- Subcommissural annuloplasty (group SCA)	35.7(6.6)	30.2(3.9)	p=0.14
p level	**p<0.001**	p=0.9	
Ejection Fraction of the LV [%]			
- External annuloplasty (group EA)	58.7 (12.1)	56.9(10.4)	p=0.57
- Subcommissural annuloplasty (group SCA)	54.2 (12.8)	60.2(10.1)	p=0.07
p level	p=0.2	p=0.4	
Mean Transaortic Gradient [mmHg]			
- External annuloplasty (group EA)	16.0(4.8)	7.0 (4.4)	p=0.2
- Subcommissural annuloplasty (group SCA)	17.5(4.9)	12.6 (4.4)	p=0.4
p level	p=0.7	**p=0.02**	
Peak Transaortic Gradient [mmHg]			
- External annuloplasty (group EA)	29.0(9.8)	14.4 (7.7)	**p<0.001**
- Subcommissural annuloplasty (group SCA)	24.0(9.3)	20.0(7.6)	p=0.1
p level	p=0.8	**p=0.013**	
Width of the Aortic Regurgitant Jet [mm]			
- External annuloplasty (group EA)	11.1 (1.9)	2.94 (3.0)	**p<0.001**
- Subcommissural annuloplasty (group SCA)	9.9 (5.1)	3.17(3.5)	**p=0.001**
p level	p=0.28	p=0.8	

Source: by the author

4. Discussion

The presence of a bicuspid aortic valve (BAV) is associated with a high incidence of valve dysfunction, proximal aortic dilatation, and an increased risk of acute aortic events. Tzemos et al. reported cardiac events in 25% of patients and aortic dilatation in 45% of a cohort of 650 individuals over a nine-year follow-up period [18]. Similarly, in the Olmstead County study by Sarano et al., which followed an asymptomatic BAV population for 15 years, 42% experienced cardiac events and 27% eventually required cardiac surgery [19]. Thanasoulis identified predictors of aortic dilatation in 582 BAV patients, notably moderate to severe aortic insufficiency and the fusion of the right and left aortic valve leaflets [20]. Current clinical guidelines recommend valve-sparing operations for patients presenting with isolated aortic valve insufficiency [21].

In this single-center study, BAV repair combined with aortic root management proved both feasible and effective. The surgical approach resulted in 100% mid- and long-term survival, with satisfactory freedom from reoperation and stability of the repair. However, the durability of BAV repair appeared somewhat inferior compared to repairs of tricuspid aortic valves. This difference may be attributed to an underlying connective tissue disorder, a common feature in patients with BAV [22]. Progressive annular dilatation due to annuloaortic ectasia may also compromise the long-term stability of the repair. Therefore, our study further explored the impact of different annular stabilization techniques on echocardiographic outcomes.

Echocardiographic findings demonstrated that systolic cusp mobility remained well preserved following external annuloplasty (EA) but was somewhat diminished after subcommissural annuloplasty (SCA). This likely accounts for the lower transvalvular velocities and gradients observed in the EA group. Additionally, the EA technique significantly reduced the aortic annulus diameter two years postoperatively, which may explain the inferior performance of SCA reported in previous comparisons with valve-sparing root reimplantation (VSRR) in patients with large annuli [23]. Vallabhajosyula and colleagues found that a preoperative ventriculo-aortic junction diameter of 28 mm or more was associated with a higher recurrence rate of aortic regurgitation (grade >1+) following SCA than VSRR. However, in patients with smaller annuli, the durability of both approaches was comparable [24]. In our cohort, both groups had similarly enlarged annuli in the 27–28 mm range prior to surgery.

Our findings showed significant reverse remodeling of the left ventricle (LV) after BAV repair, evident both early and at medium-term follow-up. Importantly, this remodeling was comparable between the two annuloplasty techniques, although EA offered superior hemodynamic performance, as indicated by transaortic flow on Doppler echocardiography. We propose that more advanced imaging modalities, such as speckle tracking for regional deformation or three-dimensional volumetry, may be more sensitive in detecting subtle differences in LV function between groups.

Annuloplasty techniques remain under clinical investigation. It is well-established that suture-based SCA is prone to failure due to late redilatation of the aortic root. In contrast, root stabilization through reimplantation has demonstrated superior long-term outcomes compared to SCA alone [25,26]. Promising results have also been reported with internal and external annuloplasty rings [27,28]. Consistent with our findings, Schaefers et al. documented good durability of subcommissural or circular annuloplasty when combined with aortic root remodeling or replacement [29].

In conclusion, BAV repair is a safe procedure offering favorable short- and midterm outcomes. External annuloplasty is associated with superior annular stabilization and more favorable hemodynamic performance compared to subcommissural annuloplasty. We believe that the long-term durability of BAV repair can be further enhanced by more aggressive stabilization of the aortic root, particularly at the level of the ventriculo-aortic junction.

5. Conclusion

This study demonstrates that bicuspid aortic valve (BAV) repair, when performed with appropriate surgical techniques and combined with aortic root management, is a safe and effective procedure, yielding excellent short- and midterm survival. The findings highlight that external annuloplasty provides superior annular stabilization and improved hemodynamic performance compared to subcommissural annuloplasty, particularly in patients with annular dilatation. Moreover, the durability of BAV repair is significantly enhanced when accompanied by valve-sparing aortic replacement procedures. Given the progressive nature of aortopathy in BAV patients, careful selection of the annuloplasty technique and consideration of root stabilization at the ventriculo-aortic junction are critical to ensuring long-term repair success. Further long-term follow-up and prospective comparative studies are warranted to validate these findings and refine surgical strategies for BAV repair.

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Data Availability Statement: Data is available at request. Please contact the corresponding author for any additional information on data access or usage.

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