

Reimplantation versus aortic ring annuloplasty in bicuspid valve with borderline aortic root ectasia



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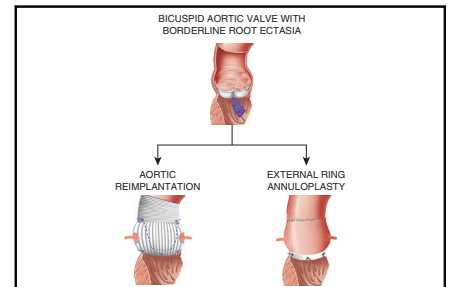
ABSTRACT

Objective: Bicuspid aortic valve repair can be achieved with the reimplantation technique or external ring annuloplasty. Reimplantation could be an “overtreatment” in nonaneurysmatic aortic roots. External ring repair, on the contrary, could be an “undertreatment” in dilated roots. The aim of this retrospective study is to compare the 2 techniques in patients with borderline aortic root dimensions, analyzing early results, aortic regurgitation recurrence, and root dilation over time.

Methods: We selected patients with bicuspid aortic valve and ectasia of the aortic root (40-48 mm) who underwent reimplantation or external ring repair. We compared the 2 techniques, analyzing immediate postoperative and follow-up echocardiography. Only patients with at least 1 year of follow-up were included.

Results: We obtained 2 groups of 21 patients (reimplantation) and 22 patients (external ring). Median follow-up time was 36 (40) months. There were no deaths during the follow-up periods. Three patients required reoperation in the external ring group because of recurrent aortic regurgitation, with a freedom from reoperation of 77.8% at 7 years (no reoperation was required in the reimplantation group). In the external ring group, we observed an immediate postoperative root diameter reduction and no significative expansion during follow-up (+0.4 mm/year, $P = .184$).

Conclusions: Excellent results of reimplantation technique are confirmed and stable over time. Root diameter seems to remain stable over time when external ring technique was performed. The greater incidence of reoperation after external ring could be due to the progressive learning curve (256 patients vs 52 patients). Longer follow-up studies are needed. (JTCVS Techniques 2022;15:36-45)



Two different approaches in bicuspid aortic valve with borderline root ectasia.

CENTRAL MESSAGE

Reimplantation is more complex but guarantees excellent results; external ring appears a good alternative in most cases and, despite a greater incidence of reoperation, guarantees stable root diameter.

PERSPECTIVE

Patients with rare features may not perform well with a standard approach and could need more personalized management. In patients with aortic bicuspid valve and ectatic aortic root requiring a valve repair, the reimplantation could be an “overtreatment,” whereas a valve repair alone could be an “undertreatment.” We focus on this choice, hoping to stimulate a reflection on a more tailored approach.

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Abbreviations and Acronyms

AR	= aortic regurgitation
BAV	= bicuspid aortic valve
ER	= external ring annuloplasty

Over the past 20 years, bicuspid aortic valve (BAV) repair has become a valid alternative to conventional aortic valve replacement, with excellent hemodynamic and survival results.¹⁻⁴ Stabilizing the aortic annulus at the time of surgery has been shown to significantly improve the durability of BAV repair. In fact, the diameter of the virtual basal ring, the plane passing through the nadir of the 3 cusps, is related to aortic regurgitation (AR) severity, and an untreated dilated aortic annulus is a major risk factor for failure of aortic valve repair.⁵⁻⁸

In our recent anatomical study, we compared aortic reimplantation with the Valsalva graft, the Dacron graft with neosinuses (Terumo Aortic), with aortic external ring annuloplasty in BAVs, analyzing their morphologic features with computed tomography scanning. We found that both reimplantation with Valsalva graft and external ring annuloplasty achieve an efficient aortic annuloplasty with similar anatomical and functional results on BAVs in terms of effective height, the orthogonal distance from the central free margins, and the aortic annulus and coaptation length, the distance of cusp apposition in diastole.⁹

BAV repair can be achieved among a variety of surgical techniques depending on the type of BAV pathology, through an aortic reimplantation procedure (David) or external ring (ER) annuloplasty. The first approach could be an “overtreatment” in case of nonaneurysmatic aortic root. The second approach, on the contrary, could be an “undertreatment” in the case of dilated root. The aim of the study was to retrospectively compare the 2 techniques in patients with borderline aortic root dimensions (between 40 and 48 mm), analyzing early results, AR recurrence, and root dilation over time.

METHODS

Ethics Statement

The study was approved by European Hospital Ethical Committee (No. IRB 2021/01 on January 15, 2021). Informed consent was waived because of the retrospective nature of the study with anonymous clinical data analysis.

Patients

From January 2000 to April 2020, 308 patients underwent an aortic valve-sparing/repair procedure at European Hospital of Rome. We retrospectively selected patients with a BAV, excluding patients operated on during the last year, to guarantee at least 1-year follow-up, and then we divided them into 2 groups: patients who underwent an aortic reimplantation procedure versus patients who underwent external aortic ring annuloplasty. Then, we selected among the 2 groups only patients who had a preoperative

aortic root diameter between 40 and 48 mm. Patients retrospectively selected for the study were operated between 2012 and 2020 for the reimplantation group and between 2014 and 2020 for external ring repair group, because in the first period of our experience, we mostly treated patients with normal tricuspid valves. The study design and baseline characteristic of patients are summarized in [Figure E1](#) and [Table 1](#).

Each patient underwent preoperative and postoperative echocardiography in our echo-lab. For each patient, we collected the following measures: ejection fraction, left ventricle end-diastolic diameter and volume, left ventricle end-systolic diameter and volume, grade of mitral and aortic regurgitation, aortic transvalvular gradients (mean and peak gradient), aortic diameters at level of virtual basal ring, aortic root, sinotubular junction (STJ), and tubular tract of ascending aorta ([Figure E2](#)). The root diameters were measured both in parasternal long-axis view and parasternal short-axis view, in diastolic phase, from inner edge to inner edge. The largest measure was considered. AR was assessed with vena contracta, EROA PISA (ie, effective regurgitant orifice area—proximal isovelocity surface area), regurgitant volume, and diastolic reflux in descending aorta (end diastolic flow velocity): severity was defined in accordance with European Society of Cardiology guidelines.

Surgical Technique

Our experience in the reimplantation technique started 20 years ago and has been previously described, initially only for tricuspid aortic valves, and since 2012 reimplantation has been performed also in BAVs. It has been standardized and has not undergone significant modifications ([Figure 1, A](#))^{10,11}; meanwhile our experience in aortic valve repair technique with external ring annuloplasty started in 2014 and has been described in our recent publication ([Figure 1, B](#)).⁹ Surgical indication was given according to current European Association for Cardio-Thoracic Surgery/European Society of Cardiology guidelines for aortic valve regurgitation and/or supracoronary aortic aneurysm; all procedures were performed by the same experienced surgeon; the choice between reimplantation and aortic valve ring repair was evaluated for each specific case, according to the surgeon's experience. In brief, in the external ring repair technique, root dissection is performed in the same fashion as for a reimplantation procedure. Horizontal 2/0 pledgeted sutures are placed along the circumference of the virtual basal ring, from inside out. Care is taken to avoid any distortion of the valve leaflets. Then, the external ring is a made by using a 5- to 7-mm wide Teflon strip with a length tailored to reduce the internal annulus diameter to 21 to 23 mm and to re-establish a 1:1.3 ratio with the STJ diameter. Usually, it corresponds to a strip of 8 to 9 cm in length. The strip is placed outside the aortic root base, around the virtual basal ring passing it beneath the coronary ostia. The subannular sutures are then passed through the Teflon strip and tightened on a Hegar's dilator, positioned across the aortic valve, to avoid excessive annular reduction. The Hegar's dilator size is chosen according to the desired annular dimensions (usually between 21 and 23 mm). Then, the cusp effective height is assessed with a caliper and any cusp prolapse is corrected by free margin plication with 5/0 polypropylene suture, to obtain a 9 to 10 mm effective height for both cusps. The transected ascending aorta is then sutured back at the STJ. In the presence of a dilated ascending aorta, a Dacron graft of proper size is used using a standard technique. In the external ring group, associated ascending aorta replacement was performed in 11 patients (50%). Associated aortic leaflet plication was performed in 14 patients (67%) in the reimplantation group and in all patients (100%) in the external ring group. Operative data are summarized in [Table 1](#). Intraoperative pre- and postprocedural transesophageal echocardiography was performed for each patient, especially to verify postprocedural results. The postoperative transesophageal echocardiography commonly reports the function of the aortic valve. All anatomical details of the root were taken few days after surgery. In no case did the transesophageal echocardiogram reveal an AR > 1+, and there was no need for a second run to convert to another procedure. Intraoperative

TABLE 1. Baseline characteristics and operative data

	External ring	Reimplantation	P value
N	22	21	
Male sex, n (%)	22 (100%)	20 (95%)	.3
Age, y	44.5 (13)	47 (24)	.47
Height, cm	176.5 (11.5)	180 (13)	.37
Weight, kg	76 (11.5)	81 (16.5)	.36
Body surface area, m ²	1.9 (0.2)	2 (0.2)	.22
BAV	22	21	
Fused BAV	15 (68%)	15 (71%)	.81
2-sinuses BAV	7 (32%)	6 (29%)	.81
Echo findings			
EF, %	62 (10)	56 (7.5)	.99
LVEDD, mm	59 (13)	52 (8)	.11
LVESD, mm	39.5 (9.5)	37 (10.5)	.29
LVEDV, mL	151.5 (64.5)	118 (83)	.24
LVESV, mL	64.5 (31)	49 (39.5)	.23
Mitral regurgitation > 2+, n (%)	2 (9%)	1 (5%)	.58
Aortic regurgitation, none	0 (0%)	2 (9%)	.14
Aortic regurgitation, trivial	0 (0%)	10 (48%)	< .01
Aortic regurgitation, mild	5 (23%)	0 (0%)	.2
Aortic regurgitation, moderate	0 (0%)	2 (9%)	.14
Aortic regurgitation, severe	17 (77%)	7 (33%)	< .01
Aortic regurgitation with eccentric jet	16 (73%)	11 (52%)	.17
Aortic annulus Ø, mm	25.5 (1.75)	27 (3)	.10
Aortic root Ø, mm	41 (3.5)	46 (2.5)	< .01
Range aortic root Ø, mm	40-47	43-48	
Sinotubular junction Ø, mm	37.5 (4)	44 (5)	< .01
Ascending aorta Ø, mm	44 (13.5)	51 (7.5)	< .01
CBP time, min	88.5 (15)	111 (22)	< .01
Crossclamp time, min	75 (15)	100 (24.5)	< .01
Associated ascending aorta replacement (external ring group)	11 (50%)	–	
Graft Size (Valsalva), in reimplantation	–		
32 mm		17 (81%)	
30 mm		2 (9.5%)	
28 mm		2 (9.5%)	
Graft size (straight), in ascending aorta replacement*		–	

(Continued)

TABLE 1. Continued

	External ring	Reimplantation	P value
30 mm	8 (72%)		
28 mm	3 (28%)		
Cusp plication	22 (100%)	14 (67%)	.03
Associated other cardiac surgery	2 (9%)	2 (9%)	.96

BAV, Bicuspid aortic valve; EF, ejection fraction; LVEDD, left ventricle end-diastolic diameter; LVESD, left ventricle end-systolic diameter; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume; CPB, cardiopulmonary bypass. *Ascending aorta replacement was performed in 11 patients in the external ring group.

postprocedural results were overlapping to postoperative data performed in the first postoperative week, which are reported in Table 2.

Follow-Up

To better address our end point of aortic root diameter variation, we decided to exclude patients with less than 1-year follow-up. Clinical follow-up was made by a telephone interview performed by a physician/surgeon, whereas echocardiographic follow-up was made, when possible, in our echo-lab or acquiring reports and image from patients (for examinations performed elsewhere).

Statistical Analysis

All data processing was carried on a workstation running IBM-SPSS 26 (IBM Corp) on a Windows 10 machine (Microsoft Corp). Categorical variables were presented as numbers and percentages and were analyzed by the Pearson χ^2 or Fisher exact test. Continuous variables were expressed as mean with standard deviation or median with interquartile range. Normality of the data was assessed using the Shapiro–Wilk test. Differences between groups were compared using the Student *t* test for normally distributed continuous variables while for non-normally distributed continuous variables the Mann–Whitney *U* test was used, paired *t* test was used in comparisons within the same groups. Mortality and morbidity (reoperation) are presented as incidences, and all plots were determined according to the Kaplan–Meier method; the log-rank test was used to verify differences among cohorts when appropriate.

RESULTS

After the selection procedure, we had 79 patients with bicuspid valve who an aortic valve–sparing operation and had at least 1 year follow-up; of them, 46 patients received a reimplantation procedure, whereas 33 received an external ring annuloplasty. Once the further selection, based on aortic root diameter between 40 and 48 mm, was made, we had 2 groups of 21 reimplantation patients and 22 external ring patients. No patient in the selected groups had Marfan syndrome or other connective tissue disorders; all patients were operated electively (no acute aortic syndromes) (Figure E1).

Cardiopulmonary bypass time and crossclamp time were, as expected, longer in the reimplantation group (cardiopulmonary bypass: external ring 88.5 [15] minutes vs reimplantation 111 [22] minutes, *P* < .01; crossclamp time: external ring 75 [15] minutes vs reimplantation 100 [24.5] minutes, *P* < .01). Most of the anthropometric and echocardiographic features were homogeneous between the 2

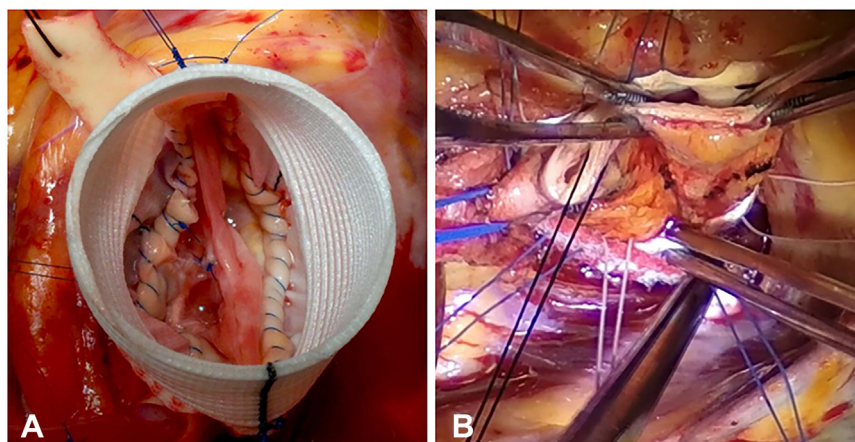


FIGURE 1. A, Intraoperative image of aortic reimplantation of a bicuspid aortic valve with borderline root ectasia/B, Intraoperative image of external ring annuloplasty of a bicuspid aortic valve with borderline root ectasia.

groups, except for aortic diameters, where despite the selection procedure, a slight but significant difference persisted: aortic root (reimplantation 46.0 [2.5] vs external ring 41 [3.5], $P < .01$), STJ (44 [5] vs 37.5 [4], $P < .01$), and ascending aorta (51 [7.5] vs 44 [13.5], $P < .01$); also, the grade of preoperative AR differed between the 2 groups: severe AR (reimplantation 33% vs external ring 77%, $P < .01$). Overall, this is a cohort study with specific differences in patient characteristics.

TABLE 2. Postoperative outcomes and echocardiograph*

	External ring	Reimplantation	P value
N	22	21	
Operative deaths	0	0	
Postoperative complications			
Cerebral ischemia (transient)	1	1	.97
Revision for bleeding	3	1	.32
Atrial fibrillation	3	4	.63
Mean ICU stay, d	1 (1)	2 (2)	.60
Mean 24 h bleeding, mL	690 (265)	755 (923)	.85
Postoperative echocardiography			
AR >2+	0	0	
EF, %	57.5 (7)	53 (11)	.53
Mean gradient, mm Hg	10.5 (6)	9 (6)	.95
Peak gradient, mm Hg	18 (10)	14.5 (13)	.39
Aortic root diameter, mm	38 (4)	–	<.01†
Median aortic root diameter variation, mm	–4 (5)	–	

ICU, Intensive care unit; AR, aortic regurgitation; EF, ejection fraction. *Postoperative echocardiography was performed in the first postoperative week. †Comparison with preoperative root diameter.

Early Outcome: Clinical

There were no operative deaths in the 2 groups nor any ischemic complications during the hospital stay. Three patients in the reimplantation group required drainage for pericardial effusion, and 1 patient in the external ring group required hemostatic surgical revision.

Early Outcome: Echocardiographic

In both groups, no patient was discharged with an AR greater than mild (1+). Pressure gradients across the valve at discharge were, respectively, for external ring repair and reimplantation, 10.5 (6) mm Hg versus 9 (6) mm Hg (mean), 18 (10) versus 14.5 (13) (peak), with no significance difference (Table 3). Aortic root diameter was found to be reduced also in patients who underwent external ring valve repair: 38 (4) mm (preoperative was 41 [3.5] mm, $P < .01$), mean reduction was –4 (5) mm. This reduction was slightly more pronounced in patients who also received a supracoronary aorta replacement (37 [4] mm) (when compared with patient who didn't (40 [4.5] mm)); the difference was not significant.

Late Outcome: Clinical

Clinical and echocardiographic follow-up was 100% complete, and median follow-up time was 36 (40) months. There were no late deaths in either group, nor thromboembolic or hemorrhagic events. One instance of infective endocarditis occurred in the external ring group, causing severe aortic regurgitation and reintervention. Two other patients in external ring group developed severe AR and underwent reoperation as well. No patient was reoperated in the reimplantation group. Therefore, freedom from reoperation was 100% for reimplantation group until the end of the follow-up period, whereas for external ring group was 77.8% (Figure 2).

TABLE 3. Follow-up (median follow-up time 36 [40] months)

	External ring	Reimplantation	P value
N	22	21	
Deaths	0	0	
AR >2+	3	0	.08
Reoperation	3	0	.08
Echo findings (excluded reoperated patients)			
EF, %	60 (10)	60 (14.5)	.42
LVEDD, mm	50.5 (9)	50 (9.5)	.88
LVESD, mm	33 (12.5)	33 (12.5)	.38
LVEDV, mL	112.5 (39)	108 (79)	.70
LVESV, mL	43.5 (25.5)	43 (55.5)	1.00
Aortic regurgitation, none to trivial ($\leq 1+$)	17 (89%)	19 (90%)	
Aortic regurgitation, mild (2+)	2 (11%)	2 (10%)	
Aortic regurgitation, moderate (3+)	0	0	
Aortic regurgitation, severe (4+)	0	0	
Aortic root \emptyset , mm	38.5 (8)	–	

AR, Aortic regurgitation; EF, ejection fraction; LVEDD, left ventricle end-diastolic diameter; LVESD, left ventricle end-systolic diameter; LVEDV, left ventricle end-diastolic volume; LVESV, left ventricle end-systolic volume.

Late Outcome: Echocardiographic

Once we excluded patients who underwent reoperation, no other patient in either group developed an AR greater than mild over the follow-up period. Residual AR was mild or less in the totality of patients in both groups. Trans-aortic pressure gradients remained stable over time in both groups without significant differences (Table 3). In the external ring group, aortic root dimensions did not vary significantly over time; after the immediate postoperative reduction, mean root diameter went from 38 (4) mm to 38.5 (8), with a mean cumulative increase of 1.8 mm ($P = .18$). When this diameter variation was considered over time and weighted for each patient follow-up period, the mean variation was +0.4 mm/year (Figure 3).

DISCUSSION

During the last 2 decades, BAV repair has received a strong boost, becoming a valid alternative to conventional aortic valve replacement, with excellent mid- and long-term results.¹² In general, the BAV repair usually comprises the plication of the free margins of the prolapsing cusps to correct the prolapse plus an annuloplasty suture or ring to correct annular dilatation and stabilize the repair. Moreover, stabilization of the STJ may require a ring placement or, more frequently, the ascending aorta replacement.¹³ Alternatively, the reimplantation procedure allows at the same time aortic root replacement and aortic annular stabilization, with excellent long-term results.^{11,14,15}

Surgical treatment of patients with BAV with borderline aortic root diameters is still under debate. Indeed, even if according to the current guidelines¹⁶ a slightly dilated aortic root (<45 mm) would not require a root replacement, a more aggressive approach with aortic reimplantation has been proposed to stabilize the functional aortic annulus more completely both at the level of the virtual basal ring and at the STJ and restoring the valve symmetry at the same time,¹⁵ taking into account the idea of the functional aortic annulus as a single anatomofunctional unit composed by the STJ, the basal ring of the aortic valve, and the crown-like attachment of the aortic leaflets. As a matter of fact, the analysis of root configuration and commissural orientation has provided a fundamental contribution in the field of BAV repair, encouraging root replacement even with borderline diameters, if performed in selected patients at experienced centers when durable results are expected in the context of valvular repair. In contrast, a root replacement in case of borderline surgical dimensions may represent an “overtreatment” of the BAV pathology, which may be addressed by an aortic annuloplasty and leaflet repair without root replacement. In deciding for root replacement, the surgeon should take into consideration the increased complexity of the reimplantation procedure and weight it against the uncertain fate of nonreplaced root. In this respect, and based on our experience, we tend to favor a more aggressive approach by replacing the root when the diameter approach 42 to 44 mm or when the root wall appears thin and fragile.

Following up on our recent anatomical study in which we demonstrated an efficient annuloplasty in terms of effective height and coaptation length, both in reimplantation and in external ring technique,⁹ we decided to compare the fate of nonreplaced root treated by external ring annuloplasty, with the already-standardized reimplantation technique, in patients with borderline BAV root ectasia. As expected, reimplantation procedure has confirmed stable results over time, guaranteeing 100% freedom from AR greater than mild and consequently 100% freedom from reoperation until the end of the follow-up period.

In the external ring group, 3 patients required reoperation for recurrence of severe AR, one of them for a technical issue in correcting the cusp prolapse, and another one suffered an immediate intraoperative right coronary compression from the displacement of the external annuloplasty ring. To solve the problem, the ring was transected, which led to progressive annular enlargement and recurrence of AR; the third patient experienced postoperative infective endocarditis, which also recurred later after prosthetic valve replacement. Therefore, the greater incidence of reoperation (freedom for reoperation 77.8% at 6 years in ER group vs 100% at 8 years in the reimplantation group) could be probably due to a progressive learning curve (256 vs 52 patients undergoing reimplantation and external ring annuloplasty, respectively). Once we excluded patients who

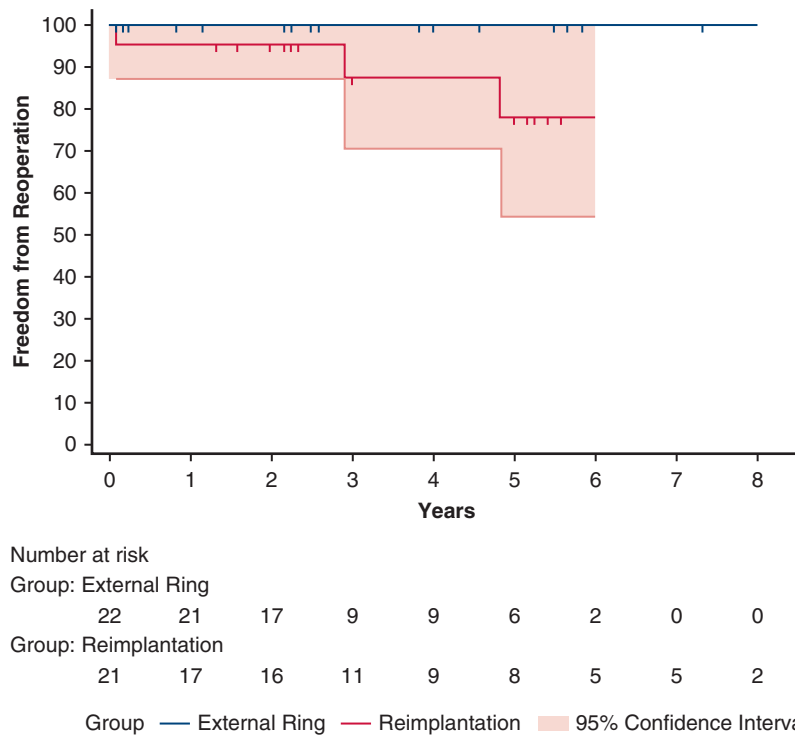


FIGURE 2. Freedom from reoperation (Red: Aortic reimplantation; light blue: external ring annuloplasty, 95% confidence interval).

underwent reoperation for these specific issues, no other patient developed an AR greater than mild during follow-up.

Patients in the ER group had a greater degree of preoperative AR: we wonder whether it could be considered a potential risk factor for repair failure, but in the light of the specific failure causes we found, we are not confident with this assumption; furthermore, due to the small sample size, we did not perform a focused regression analysis either.

The interesting result is the fate of nonreplaced root: after a significant immediate postoperative root diameter decrease (37.6 [3.2] mm vs 42.4 [2.3] mm of preoperative,

$P < .01$) with a mean reduction of -3.2 (2.9) mm, the aortic root dimensions remained stable and did not vary significantly over time (mean variations $+0.4$ mm/year).

These data may be important to take into consideration in the case of patients with borderline BAV root ectasia. In fact, it is important to weight the complexity of the radical intervention against a less-aggressive procedure, which seems to guarantee, however, a root stability over time, despite a slightly increased incidence of reoperation, which needs to be confirmed by a larger number of patients and after a firm learning curve.

EXTERNAL RING REPAIR: FATE OF THE NON-REPLACED AORTIC ROOT

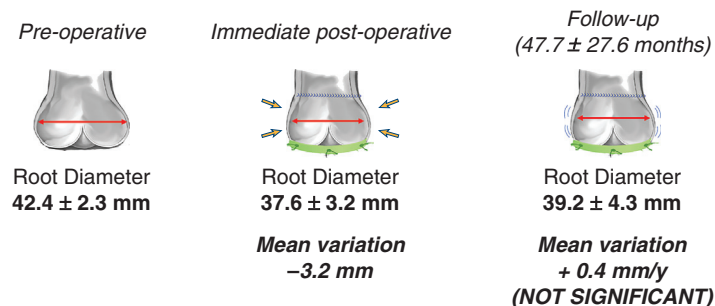
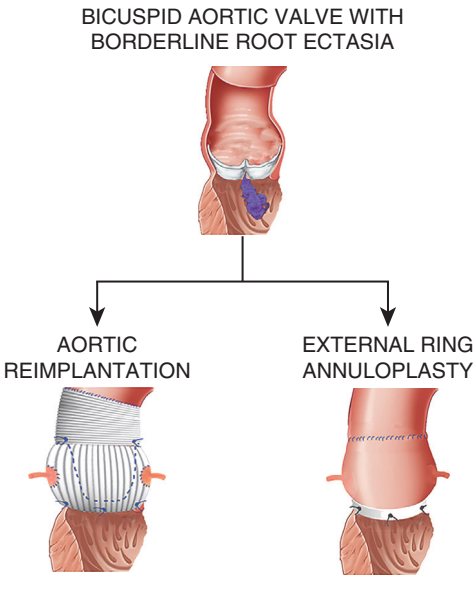
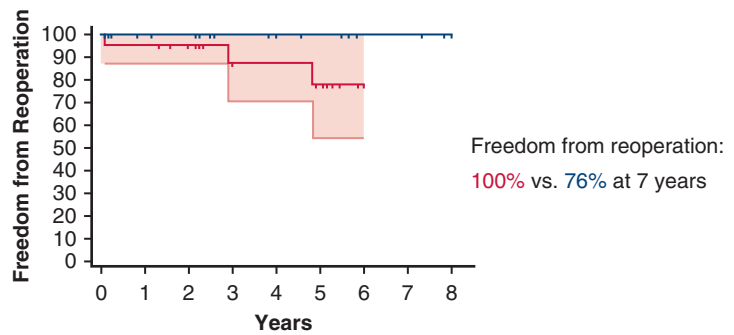


FIGURE 3. Schematic representation of fate of nonreplaced aortic root in patients undergoing the external ring procedure: after the immediate postoperative reduction, aortic root dimensions did not vary significantly over time.

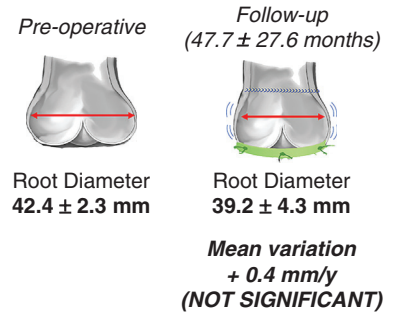
Reimplantation versus Aortic Ring annuloplasty in bicuspid valve with borderline aortic root ectasia

Methods: Patients with bicuspid aortic valve and aortic root ectasia were retrospectively selected; patients who received reimplantation procedure and patients who received external ring repair were compared.

Results:
 Valve outcome: 3 reoperations in ER group
 0 reoperation in reimplantation group



Root Outcome:
 No significant expansion over years
 In ER group



Implication: An higher incidence of recurrent AR was observed in ER group; meanwhile aortic root destiny seems not to be affected. We look forward for a most tailored approach for specific subset of patients.

FIGURE 4. Schematic representation of the 2 surgical approaches for bicuspid aortic valve repair with borderline root ectasia; Root diameter seems to remain stable over time when the external ring technique was performed. The greater incidence of reoperation after the external ring technique could be due to the progressive learning curve (256 patients vs 52 patients). ER, External ring; AR, aortic regurgitation.

Limitations

This study refers to a single-center experience, with patients operated by a single surgeon during 2 learning periods. Even if encouraging, these results should be considered carefully. Due to the small sample size of the study, the quite-short median follow-up time, and the relative very low number of time-related events, a statistically interpretation of the outcomes cannot be conclusive.

Furthermore, must be emphasized that, considering relative rarity of the pathology and the peculiar characteristics of these patients, it was difficult to obtain to completely homogeneous groups, and a treatment allocation bias was unavoidable. Nevertheless, despite those premises, this study can be considered as a hypothesis-generating study that should be verified in larger studies.

Our echocardiographic follow-up was only partially performed in our echo-lab, and we also judged adequate some examinations performed outside our lab. However, we

always considered adequate the reporting center in assessing the functional result of the aortic valve.

CONCLUSIONS

Excellent results of reimplantation technique are confirmed and are stable over time. Root diameter in borderline patients with BAV seems to remain stable over time when treated with the external ring technique. The greater incidence of reoperation after the external ring procedure appears to be due to the progressive learning curve (256 patients vs 52) (Figure 4). Larger studies with longer follow-up are needed.

Conflict of Interest Statement

As inventor of the Valsalva graft described in the manuscript, Prof De Paulis has received in the past royalties from Terumo Aortic. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: bicuspid aortic valve, aortic reimplantation, external aortic ring annuloplasty, aortic root aneurysm

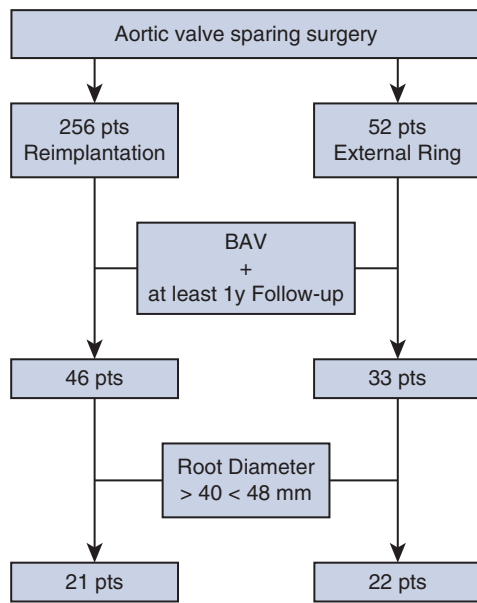


FIGURE E1. Flow chart of retrospective patient selection. *BAV*, Bicuspid aortic valve.

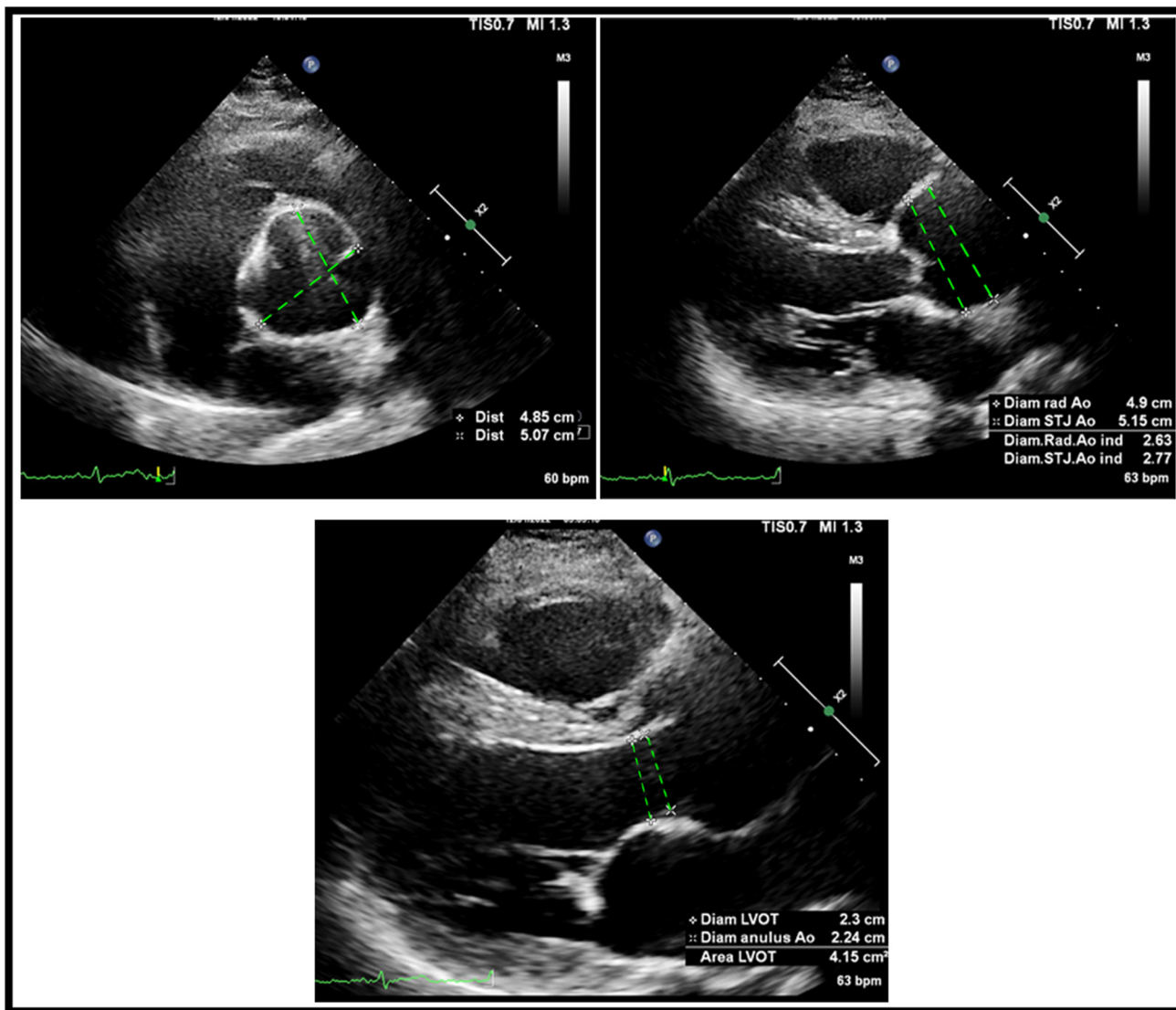


FIGURE E2. The root diameters were measured both in parasternal long-axis view and parasternal short-axis view, in diastolic phase, from inner edge to inner edge. The largest measure was considered. Aortic regurgitation was assessed with vena contracta, EROA PISA (ie, effective regurgitant orifice area—proximal isovelocity surface area), regurgitant volume, and diastolic reflux in descending aorta (end-diastolic flow velocity): severity was defined in accordance with the European Society of Cardiology guidelines.