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The role of annular dimension and annuloplasty in tricuspid aortic valve repair†

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Abstract

OBJECTIVES: Valve sparing reimplantation can improve the durability of bicuspid aortic valve repair compared with subcommissural annuloplasty, especially in patients with a large basal ring. This study analyses the effect of basal ring size and annuloplasty on valve repair in the setting of a tricuspid aortic valve.

METHODS: From 1995 to 2013, 382 patients underwent elective tricuspid aortic valve repair. We included only those undergoing subcommissural annuloplasty, valve sparing reimplantation or no annuloplasty and in whom intraoperative transoesophageal echocardiography images were available for retrospective pre- and post-repair basal ring measurements ($n = 323$, subcommissural annuloplasty: 146, valve sparing reimplantation: 154, no annuloplasty: 23). In a subgroup of patients with available echocardiographic images, basal ring was retrospectively measured at the latest follow-up or prior to reoperation. subcommissural annuloplasty and valve sparing reimplantation were compared after matching for degree of aortic regurgitation and root size.

RESULTS: All three groups differed significantly for most of preoperative characteristics. Hospital mortality was 0.9%. The median follow-up was 4.7 years. At 8 years, overall survival was 80 ± 5%. Freedom from reoperation and freedom from aortic regurgitation >1+ were 92 ± 5% and 71 ± 8%, respectively. In multivariate analysis, predictors of aortic regurgitation >1+ were left ventricular end-diastolic diameter ($P = 0.003$), cusp repair ($P = 0.006$), body surface area ($P = 0.01$) and subcommissural annuloplasty ($P = 0.05$). In subcommissural annuloplasty, freedom from aortic regurgitation >1+ was lower for patients with basal ring ≥28 mm compared with patients with basal ring <28 mm ($P = 0.0001$). In valve sparing reimplantation, freedom from aortic regurgitation >1+ was independent of basal ring size ($P = 0.38$). In matched comparison between subcommissural annuloplasty and valve sparing reimplantation, freedom from aortic regurgitation >1+ was not significantly different ($P = 0.06$), but in patients with basal ring ≥28 mm, valve sparing reimplantation was superior to subcommissural annuloplasty ($P = 0.04$). Despite similar intraoperative reduction in basal ring size in subcommissural annuloplasty and valve sparing reimplantation, patients with subcommissural annuloplasty exhibited greater increase in basal ring size during the follow-up compared with the valve sparing reimplantation group ($P < 0.001$).

CONCLUSIONS: As with a bicuspid aortic valve, a large basal ring predicts recurrence of aortic regurgitation in patients with tricuspid aortic valve undergoing repair with the subcommissural annuloplasty technique. This recurrence is caused by basal ring dilatation over time after subcommissural annuloplasty. With the valve sparing reimplantation technique, large basal ring did not predict aortic regurgitation recurrence, as prosthetic-based circumferential annuloplasty displayed better stability over time. Stable circumferential annuloplasty is recommended in tricuspid aortic valve repair whenever the basal ring size is ≥28 mm.

Keywords: Aortic insufficiency • Aortic valve repair • Valve sparing root replacement • Annuloplasty

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INTRODUCTION

In previous studies, we showed that the valve sparing reimplantation technique improved bicuspid aortic valve repair durability in comparison with subcommissural annuloplasty, especially in patients with a large ventriculo-aortic junction diameter, also referred to as basal ring, as measured by echocardiography [1, 2]. In order to synchronize anatomical terms used by different groups and to follow more correctly the terminology proposed by Anderson *et al.* [3], we will change the terminology 'ventriculoaortic junction' used in previous publication by the term 'basal ring' to define the circumference passing through the nadir of the aortic cusp. In those earlier works, we have also observed a greater intraoperative basal ring reduction with valve sparing reimplantation compared with subcommissural annuloplasty, as well as recurrent dilatation of the basal ring after subcommissural annuloplasty in patients requiring reoperation for recurrent aortic regurgitation. Based on these findings, we concluded that the non-circumferential stitch-based subcommissural annuloplasty technique may prove unstable over time in certain patients, thus resulting in higher risk of aortic regurgitation recurrence. On the other hand, the circumferential prosthetic-based annuloplasty provided by valve sparing reimplantation is potentially more stable over time, which would at least partially account for the better result achieved with this technique.

This study sought to assess the role of basal ring size and annuloplasty in the tricuspid aortic valve setting. In comparison with the previous bicuspid aortic valve studies, we hypothesized that the results of this study would be influenced by the inherent morphological and pathological tricuspid aortic valve specificities. To illustrate, in the tricuspid aortic valve, the basal ring is known to be smaller than in the bicuspid aortic valve, and the three-leaflet morphology allows for up to three subcommissural annuloplasty stitches to be placed instead of only two, as in the bicuspid aortic valve.

MATERIALS AND METHODS

Patient population

Data were extracted from the institutional database dedicated to aortic valve repair. We identified 382 patients who underwent elective tricuspid aortic valve sparing or repair from 1995 to April 2013. Of these patients, 166 (43%) received subcommissural annuloplasty, 162 (42%) received valve sparing reimplantation, 48 (13%) had no annuloplasty and 6 (2%) received ring-based annuloplasty. This last group was excluded from the analysis since it comprised a small number of patients undergoing techniques that were still under investigation. Of the 376 remaining patients, 323 (subcommissural annuloplasty, $n = 146$; valve sparing reimplantation, $n = 154$; no annuloplasty $n = 23$) had pre- and post-repair echocardiographic images stored in an institutional database and available for retrospective analysis. These patients represent the study cohort. The study was approved by the hospital ethics review board.

Surgical techniques

Our surgical approach of aortic regurgitation and aortic aneurysm and the techniques for aortic valve sparing and repair have been thoroughly described in previous publications [4–7]. Since the beginning of our experience with aortic valve repair, our philosophy regarding annuloplasty has followed the one applied in mitral valve repair and we have added an annuloplasty to almost any aortic valve repair with the objective to increase coaptation length and stabilize the repair. During the first two-thirds of the study period, subcommissural annuloplasty was generally performed independently to basal ring size in patients having repair for any type of aortic regurgitation (Types Ia, Ic, Id, II and III [4]) without root dilatation (defined as root size >45 mm). Occasionally, subcommissural annuloplasty was added to root remodelling performed for root dilatation. valve sparing reimplantation was mostly performed in patients with root dilatation (aortic regurgitation Type Ib [4]). However, during the last third of the study period, we have extended the indication of valve sparing reimplantation to patients with large basal ring (aortic regurgitation Type Ic [4], basal ring ≥28 mm) even in case of none-to-moderate root dilatation, as it was the case with bicuspid aortic valve [2]. The objective was to perform a potentially more efficient annuloplasty in those patients with large basal ring. In this tricuspid aortic valve setting, however, these indications were found to be less common than in bicuspid aortic valve.

Over the study period, a minority of patients had no annuloplasty. This subgroup includes patients with aortic aneurysm having supracoronary aorta replacement or root replacement with the remodelling technique. This last technique was performed until the year 2000, and replaced thereafter by the reimplantation technique. Finally, few patients did not receive any annuloplasty because of active endocarditis or subvalvular membrane.

In the study cohort, 67% of the patients were operated for aortic aneurysm with various degrees of aortic regurgitation. In patients operated for severe aortic regurgitation without aortic aneurysm, surgery was indicated in the presence of symptoms or left ventricular dysfunction according to the guidelines. In asymptomatic patients, however, surgery was indicated for left ventricular end-diastolic diameter >60 mm, which is smaller compared with guidelines recommendations [8, 9]. The rationale to perform early surgery in the context of aortic valve repair is based on our belief that long-standing regurgitation negatively impacts the quality of aortic valve tissues, which is a major determinant of reparability and repair durability. These particularities of our approach explain the relatively small left ventricular end-diastolic diameter and left ventricle end-systolic diameter diameter reported in this cohort of patients (Table 1).

Intraoperative echocardiography

Intraoperative pre- and post-repair transoesophageal echocardiography imaging was performed in all patients by means of the Sonos® 7500 ultrasound system, and the iE33 xMATRIX® post-2006 (Philips Medical Systems, The Netherlands). All examinations were conducted by an anaesthesiologist experienced in echocardiography, and results were stored in an institutional database. Pre-repair transoesophageal echocardiography was performed following anaesthesia induction and prior to aortic cannulation, whereas post-repair transoesophageal echocardiography was performed following weaning from cardiopulmonary bypass. In-depth analysis of aortic valve function and geometry was carried out during these examinations.

Follow-up

The clinical follow-up was conducted by a research nurse via outpatient visits or by telephone calls. The follow-up of patients included in aortic valve repair database is updated every 2 years. Information on survival status and valve-related complications,

Table 1: Patient demographics

	SCA group (*n* = 146)	VSR group (*n* = 154)	NAP group (*n* = 23)	*P*-values
Age (years ± SD)	61 ± 15	53 ± 16	61 ± 15	0.03[a]
Male gender	97 (66%)	137 (89%)	10 (44%)	<0.001[b]
Body surface area (±SD)	1.9 ± 0.2	2.1 ± 0.3	1.8 ± 0.2	<0.001[a]
Previous cardiac surgery	20 (14%)	20 (13%)	2 (9%)	0.8
NYHA functional class				
1	43 (30%)	85 (55%)	14 (61%)	
2	64 (44%)	48 (31%)	7 (30%)	<0.001[c]
≥3	39 (27%)	21 (14%)	2 (9%)	
Aetiology				
Degenerative	130 (89%)	126 (82%)	15 (65%)	
Marfan	0	27 (18%)	0	0.002[b]
Endocarditis	12 (8%)	1 (1%)	3 (13%)	
Other	4 (3%)	0	5 (22%)	
Indication for surgery				
Aortic regurgitation	89 (61%)	6 (4%)	7 (30%)	
Aortic dilatation	14 (10%)	50 (33%)	9 (39%)	<0.001[b]
Regurgitation + dilatation	41 (28%)	98 (64%)	5 (22%)	
Other	2 (1%)	0	2 (9%)	
Aortic regurgitation grade				
≤1	14 (10%)	52 (34%)	11 (48%)	
2	48 (33%)	45 (29%)	7 (30%)	<0.001[b]
≥3	84 (57%)	57 (37%)	5 (22%)	
LVEDD (mm ± SD)	59 ± 9	58 ± 8	53 ± 10	0.001[d]
LVESD (mm ± SD)	41 ± 10	38 ± 9	32 ± 7	0.03[b]
Left ventricular ejection fraction				
LVEF > 50%	116 (79%)	142 (92%)	22 (96%)	
LVEF 30–50%	*27 (19%)*	10 (7%)	1 (4%)	0.01[e]
LVEF < 30%	*3 (2%)*	2 (1%)	0	
Aortic diameter (mm ± SD)				
Basal ring	24 ± 3	27 ± 4	21 ± 3	0.01[b]
Sinuses of valsalva	37 ± 6	48 ± 7	33 ± 5	<0.001[b]
Sinotubular junction	32 ± 7	40 ± 8	30 ± 7	<0.001[a]
Ascending aorta	39 ± 11	42 ± 10	43 ± 13	0.004[c]

LVEF: left ventricle ejection fraction; LVEDD and LVESD: left ventricle end-diastolic and end-systolic diameter; NAP: no annuloplasty; NYHA: New York Heart Association; SCA: subcommissural annuloplasty; VSR: valve sparing reimplantation. For aetiology, other corresponds to congenital, fibroelastoma or traumatic; for indication for surgery, other corresponds to fibroelastoma or vegetation.
[a]VSR is different from SCA and NAP groups.
[b]All three groups are different from each other.
[c]SCA is different from VSR and NAP groups.
[d]NAP is different from SCA and VSR groups.
[e]SCA different from VSR.

including thromboembolism, haemorrhage, endocarditis, reoperation and cardiovascular symptoms, was obtained as defined in published guidelines [10]. Transthoracic echocardiography was carried out for all patients prior to discharge and at regular intervals during the follow-up. Transthoracic echocardiography data on valve function including degree of recurrent aortic regurgitation were recorded from transthoracic echocardiography reports. Half of the patients are followed in our institution, half are followed by referent institutions and cardiologists. The clinical and echocardiographic follow-up was available in 99.7% of patients. Overall, the median follow-up was 4.7 years [interquartile range: 2.3–7.2], with the longest reported in the subcommissural annuloplasty group (5.5 years), followed by that of valve sparing reimplantation (4.1 years) and then no annuloplasty (2.1 years).

Basal ring measurements

In all the patients, intraoperative transoesophageal echocardiography images were retrospectively reviewed by one surgeon (Laurent de Kerchove) experienced in echocardiography. Pre- and post-repair basal ring diameters were measured on the mid-oesophageal long-axis view of the aortic valve, passing through the middle of the valve. Basal ring diameter was measured from inner to inner wall at the level of cusp insertion when the valve was open (Fig. 1). When several long-axis views were available, basal ring diameter was measured on each view and the largest measurement was recorded. Measurements were rounded to the nearest millimeter.

In a subgroup of 166 patients (51%; 81 in subcommissural annuloplasty, 85 in valve sparing reimplantation), consisting of patients being followed or having aortic valve reoperation in our centre, the basal ring diameter was also retrospectively measured on the most recent transthoracic echocardiography or pre-redo transoesophageal echocardiography images stored in institutional database. On transthoracic echocardiography, basal ring was measured with application of the same landmark as on transoesophageal echocardiography, though on a parasternal long-axis view. In this subgroup, median time to last echocardiographic examination was 4.9 years (interquartile range: 2.7–6.8), with the follow-up

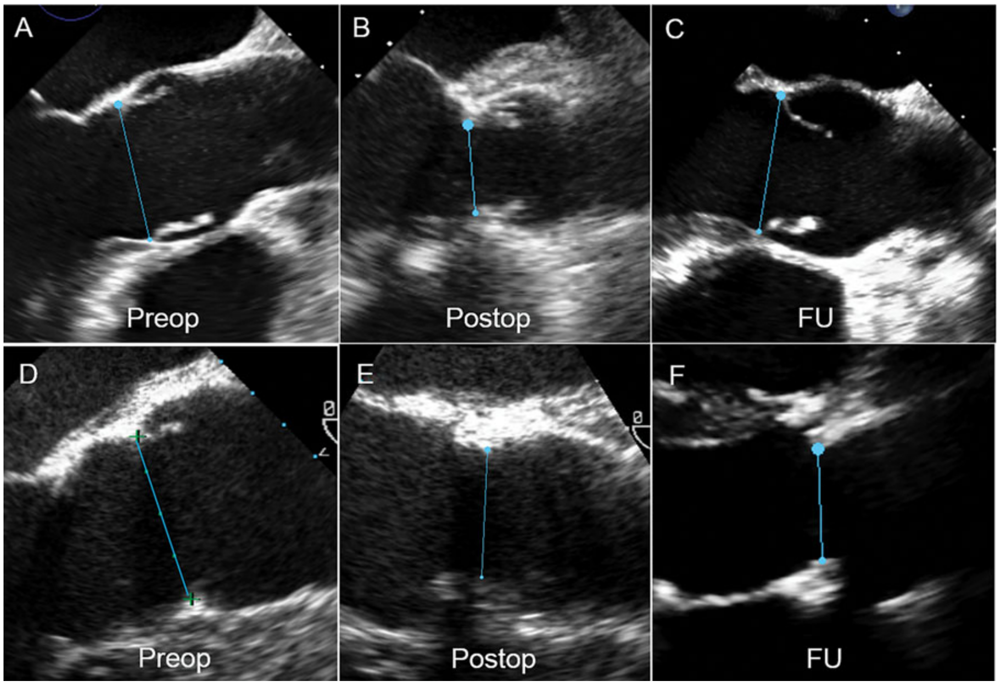

Figure 1: Echocardiographic long-axis views of the aortic valve and root. Basal ring diameter is marked by the line joining the cusp hinge point. The upper panels depict a basal ring of 29 mm pre-repair (**A**), 19 mm post-repair following subcommissural annuloplasty (**B**) and 30 mm after the 4.5-year follow-up (**C**). The lower panels illustrate a basal ring of 39 mm pre-repair (**D**), 23 mm post-repair following valve sparing reimplantation (**E**) and 24 mm after the 4.4-year follow-up (**F**).

found to be longer in subcommissural annuloplasty compared with valve sparing reimplantation (median: 5.5 years vs 4.6 years, $P = 0.01$).

Statistical analysis

Continuous data are presented as mean ± standard deviation, or as median and interquartile range for non-parametric data. Continuous variables were compared using the paired or unpaired *t*-test, as appropriate. Ordinal and non-parametric variables were compared by means of the Wilcoxon–Mann–Whitney *U*-test. Failure time data on reoperation and recurrent aortic regurgitation were analysed with the Kaplan–Meier method. The date of the first recurrent aortic regurgitation 2+ or 3+ diagnosis was recorded for time-to-event calculation. Univariate comparison between groups for failure time data was performed using the log-rank test. A proportional hazard (Cox regression) model was created so as to identify significant predictors of aortic regurgitation recurrence. Significant predictors with a *P*-value of <0.15 on the univariate analysis were input into a multivariate model. An automated stepwise forward selection process with a $P = 0.2$ probability of remaining in the model was used to identify significant predictors in the multivariate model. Recurrence of aortic regurgitation >1+ was compared in the subcommissural annuloplasty and valve sparing reimplantation groups after matching 1:1 for preoperative root size (by category: <35 mm, 35–44 mm, ≥45 mm) and degree of aortic regurgitation (by category: <2+, ≥2+), being the two variables that most determine the surgical technique used for aortic valve repair. Linear regression analysis was used to identify any significant correlation between patient characteristics and basal ring size. Significant predictors with a *P*-value of <0.15 on univariate analysis were input into a multivariate model and variable selection was made with an automatic process as seen above. Statistical analyses were carried out using the STATA 11.2 software (StataCorp, College Station, TX, USA). Graphs were created using GraphPad Prism 5.0 (San Diego, CA) and STATA. A two-tailed *P*-value of ≤0.05 was considered statistically significant.

RESULTS

Operative results

Overall, the mean age was 57 ± 16 years and 76% were male. According to surgical strategy, majority of preoperative characteristics differed significantly between the three groups (Table 1). Patients in the subcommissural annuloplasty group were older with more isolated aortic regurgitation; those in the valve sparing reimplantation group were younger with more aortic dilatation, with or without aortic regurgitation. Marfan syndrome was more commonly reported in the valve sparing reimplantation. Endocarditis was more common in the subcommissural annuloplasty and no annuloplasty groups.

Regarding intraoperative data (Table 2), aortic cusp repair, primarily indicated for cusp prolapse, was performed in a similar rate among the three groups. Cusp thinning or decalcification and cusp repair with pericardial patch were more frequent in the subcommissural annuloplasty and no annuloplasty groups. Associated procedures were also more common in the subcommissural annuloplasty and no annuloplasty groups. Cardiopulmonary bypass and aortic cross-clamp times were reported to be longer in the valve sparing reimplantation group.

Hospital mortality was 0.9% ($n = 3$) with no observable difference between groups (2 in subcommissural annuloplasty, 1 in valve sparing reimplantation and 0 in no annuloplasty; $P = 0.7$). Discharge transthoracic echocardiography imaging revealed less residual aortic regurgitation noted with valve sparing reimplantation and no annuloplasty compared with subcommissural

Table 2: Intra- and postoperative data

	SCA group (*n* = 146)	VSR group (*n* = 154)	NAP group (*n* = 23)	*P*-values
Aorta and annuloplasty techniques				
SCA	88 (60%)	0	0	–
SCA + ascending aorta replacement	53 (36%)	0	0	–
SCA + root remodelling[a]	5 (3%)	0	0	–
Ascending aorta replacement	0	0	11 (48%)	–
Root remodelling[a]	0	0	3 (13%)	–
Valve sparing reimplantation	0	154 (100%)	0	–
Aortic cusp repair techniques	92 (63%)	87 (54%)	11 (48%)	0.3
Prolapse repair[b]	66 (45%)	75 (49%)	4 (17%)	0.02[c]
Cusp thinning or decalcification	26 (18%)	12 (8%)	8 (35%)	0.02[d]
Cusp repair with patch[e]	14 (10%)	2 (1%)	4 (17%)	0.003[d]
Intraoperative aortic valve re-exploration	9 (6%)	10 (7%)	0	0.4
Associated procedures	80 (55%)	43 (28%)	10 (44%)	<0.001[f]
Cardiopulmonary bypass time (min)	96 ± 33	146 ± 31	83 ± 27	<0.001[g]
Aortic cross-clamp time (min)	72 ± 27	122 ± 24	60 ± 27	<0.001[g]
Discharge echocardiography				
No AR	22 (15%)	57 (37%)	5 (22%)	
Grade 1+	109 (75%)	93 (60%)	16 (70%)	<0.001[f]
Grade 2+	15 (10%)	4 (3%)	2 (9%)	
Peak gradient >20 mmHg	44 (30%)	10 (7%)	3 (13%)	<0.001[f]
Permanent pace maker implantation	1 (1%)	3 (2%)	0	0.5

AR: aortic regurgitation; FAA: functional aortic annulus; NAP: no annuloplasty; SCA: subcommissural annuloplasty; VSR: valve sparing reimplantation.
[a]In the SCA group: four partial root remodelling (one or two sinuses of Valsalva replaced) and one complete remodelling (three sinuses of Valsalva replaced); In the NAP group: three partial remodelling.
[b]Cusp prolapse repair techniques: central cusp plication or free margin resuspension with running sutures of Gore-Tex 7/0.
[c]NAP group different from SCA and VSR groups.
[d]VSR different from SCA and NAP groups.
[e]Cusp extension patch: 9 bovine pericardium, 6 treated or non-treated autologous pericardium.
[f]SCA different from VSR.
[g]All three groups are different from each other.

annuloplasty. Transvalvular peak gradients were reported to be lower with valve sparing reimplantation and no annuloplasty compared with subcommissural annuloplasty. The rate of permanent pace maker implantation was slightly higher in the valve sparing reimplantation group compared with subcommissural annuloplasty and no annuloplasty ($P = 0.5$). (Table 2)

Outcomes

At 8 years, the full cohort exhibited overall survival of 80 ± 7% and freedom from aortic valve reoperation was 92 ± 5%. Overall survival was higher in subcommissural annuloplasty and valve sparing reimplantation compared with no annuloplasty (subcommissural annuloplasty: 78 ± 9%, valve sparing reimplantation: 86 ± 9% and no annuloplasty: 51 ± 43%; $P = 0.02$) and freedom from aortic valve reoperation was similar in the three groups (subcommissural annuloplasty: 90 ± 8%, valve sparing reimplantation: 94 ± 5% and no annuloplasty: 100%; $P = 0.7$). Freedom from aortic regurgitation >2+ was similar in the three groups (subcommissural annuloplasty: 87 ± 9%, valve sparing reimplantation: 93 ± 5% and no annuloplasty: 93 ± 7%, $P = 0.9$) but freedom from aortic regurgitation >1+ was significantly higher in valve sparing reimplantation and no annuloplasty compared with subcommissural annuloplasty (subcommissural annuloplasty: 61 ± 12%, valve sparing reimplantation: 85 ± 7%, no annuloplasty: 88 ± 12%, $P = 0.02$).

In multivariate analysis, independent predictors of recurrent aortic regurgitation >1+ were subcommissural annuloplasty, cusp repair, left ventricular end-diastolic diameter and body surface area in the full cohort, basal ring size, body surface area and patch repair in the subcommissural annuloplasty group and cusp thinning or decalcification in the valve sparing reimplantation group (Table 3)

In the subcommissural annuloplasty group, freedom from aortic regurgitation >1+ was significantly higher in patients with a preoperative basal ring <28 mm than those with a basal ring ≥28 mm (at 5 years, 82 ± 8% vs 45 ± 25%; $P < 0.001$; Fig. 2A). In the valve sparing reimplantation group, freedom from aortic regurgitation >1+ was independent of basal ring size ($P = 0.4$; Fig. 2B). In the subcommissural annuloplasty group, freedom from aortic regurgitation >2+ and freedom from reoperation rates were also significantly higher for patients with a basal ring of <28 mm, when compared with those with a basal ring of ≥28 mm ($P < 0.001$) while in the valve sparing reimplantation group, basal ring size did not influence those outcomes ($P = 0.4$). In the no annuloplasty group, 1 patient presented with a basal ring of ≥28 mm (31 mm), this patient was the only one in this group who developed recurrent aortic regurgitation 3+ at the follow-up.

Matched comparison of subcommissural annuloplasty and valve sparing reimplantation

By matching subcommissural annuloplasty and valve sparing reimplantation groups for preoperative root size and degree of aortic regurgitation, 61 pairs were obtained. Matched groups were similar for gender, left ventricular end-diastolic diameter, EF,

Table 3: Univariate and multivariate Cox regression analysis

	Full cohort (*n* = 323)		SCA (*n* = 146)		VSR (*n* = 154)	
	P-values	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)
Univariate						
Age	0.5		0.4		0.6	
Gender (male)	0.9		0.9		0.8	
BSA	**0.01**	0.23 (0.07–0.70)	0.1		0.1	
Preoperative AR (<2 vs >2)	**0.02**	1.9 (1.1–3.4)	0.5		0.1	
LVEDD (mm)	**0.004**	1.04 (1.01–1.07)	**0.02**	1.05 (1.01–1.1)	0.1	
Root diameter (mm)	**0.004**	0.95 (0.92–0.98)	0.5		0.1	
BR diameter (mm)	0.3		**0.004**	1.14 (1.04–1.25)	0.6	
EF <30%	0.5		0.2		0.9	
SCA	**0.007**	2.2 (1.2–3.9)	–	–	–	–
Cusp repair	**0.002**	2.8 (1.4– 5.4)	**0.02**	2.7 (1.2–6.2)	0.09	
Thinning or decalcification	**0.05**	1.89 (1.00–3.6)	0.6		**0.01**	4.17 (1.3–13.1)
Patch repair	0.2		0.08		0.9	
Associated procedures	0.3		0.5		0.5	
Multivariate						
BSA	**0.01**	0.21 (0.06–0.68)	**0.007**	0.1 (0.02–0.55)	ns	
Preoperative AR (<2 vs >2)	ns		ns		ns	
LVEDD (mm)	**0.003**	1.05 (1.02–1.08)	ns		ns	
Root diameter (mm)	ns		–		ns	
BR diameter (mm)	–		**0.001**	1.2 (1.07–1.32)	–	
SCA	**0.05**	1.8 (1.0–3.25)	–		–	
Cusp repair	**0.006**	2.5 (1.3– 4.9)	ns		ns	
Thinning or decalcif.	ns		–		**0.02**	4.3 (1.3–13.9)
Patch repair	–		**0.02**	3.4 (1.2–9.5)	–	

AR: aortic regurgitation; BR: basal ring; LVEDD: left ventricular end-diastolic diameter; ns: not significant; BSA: body surface area; SCA: subcommissural annuloplasty. Bold values indicate statistically significant of *P*-values <0.05.

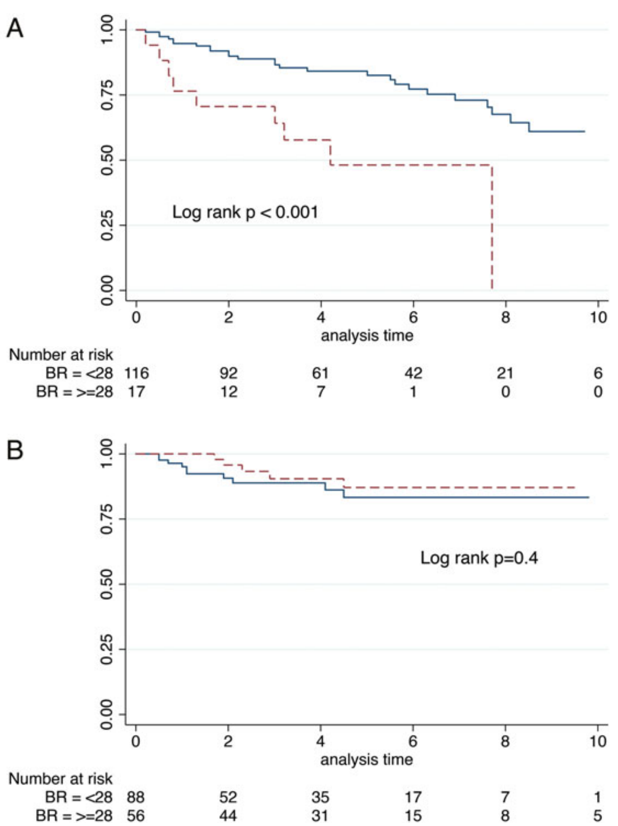

Figure 2: Freedom from recurrent AR >1+ in SCA group as a function of preoperative BR diameter <28 mm (full line) or ≥28 mm (dotted line) (**A**); and in the VSR group (**B**). SCA: subcommissural annuloplasty; BR: basal ring; VSR: valve sparing reimplantation.

cusp repair, thinning and decalcification and patch repair (*P* = ns). Matched groups remained significantly different for age (*P* < 0.001), body surface area (0.04), basal ring diameter (*P* = 0.008) and associated procedure (*P* = 0.05). Freedom from recurrent aortic regurgitation >1+ was not significantly different between matched subcommissural annuloplasty and valve sparing reimplantation groups (*P* = 0.06). However, when considering only patients with basal ring ≥28 mm, freedom from recurrent aortic regurgitation > 1+ was significantly higher in the valve sparing reimplantation group compared with the subcommissural annuloplasty group (*P* = 0.04; Fig. 3).

Analyses of basal ring diameter

The mean preoperative basal ring size of the full cohort was 25 ± 4 mm (male: 26 ± 4; female: 22 ± 3; range: 18–39). Mean indexed basal ring diameter (basal ring/body surface area) was 13 ± 2 mm.

In univariate analysis, predictors of large basal ring size were younger age (*r* = −0.29, *P* < 0.001), male gender (*r* = 0.43, *P* < 0.001), body surface area (*r* = 0.36, *P* < 0.001), left ventricular end-diastolic diameter (*r* = 0.28, *P* < 0.001), Marfan syndrome (*r* = 0.18, *P* < 0.001) and root diameter (*r* = 0.44, *P* < 0.001). In multivariate analysis, significant predictors were younger age (*P* < 0.001), male gender (*P* < 0.001), body surface area (*P* < 0.01), left ventricular end-diastolic diameter (*P* < 0.001) and root diameter (*P* < 0.001). Variables tested in linear regression analysis are listed as Supplemental Material.

Preoperative analysis revealed mean basal ring size to be the largest in the valve sparing reimplantation group (27 ± 4 mm), followed by the subcommissural annuloplasty group (24 ± 3 mm) and the no annuloplasty group (21 ± 3 mm; *P* < 0.001; Table 1).

The basal ring reduction achieved by the annuloplasty was greater with valve sparing reimplantation compared with subcommissural annuloplasty (7 ± 3 vs 5 ± 3 mm, $P < 0.001$; Table 4, Fig. 4). In the no annuloplasty group, postoperative basal ring size was similar to preoperative size (21 ± 3 vs 20 ± 3 mm, $P = 0.2$). While basal ring dilates in both groups during the follow-up compared with post-repair size, the increment was greater in the subcommissural annuloplasty group compared with valve sparing reimplantation (4 ± 3 vs 2 ± 2 mm, $P < 0.001$). Also, basal ring reduction between pre-repair and follow-up was greater with valve sparing reimplantation compared with subcommissural annuloplasty (5 ± 3 vs 1 ± 2 mm, $P < 0.001$).

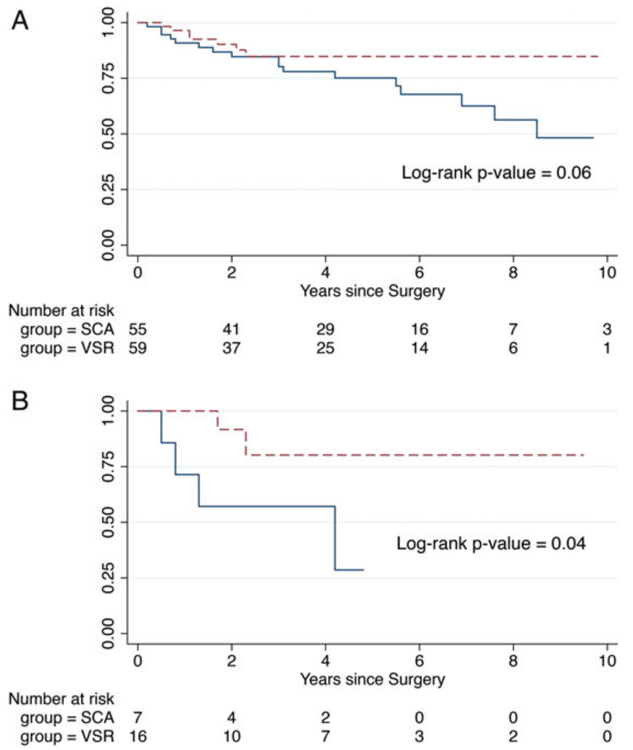

Figure 3: Matched groups comparison, freedom from recurrent AR >1+ in SCA (full line) versus VSR (dotted line) (**A**), freedom from recurrent AR >1+ in patients with preoperative basal ring diameter ≥28 mm, SCA (full line) versus VSR (dotted line) (**B**).

Analysis of basal ring variation among the different categories of preoperative basal ring size (small, medium and large; Table 4, Fig. 4) revealed greater intraoperative basal ring reduction from small to large basal ring categories in both groups ($P < 0.001$). In the valve sparing reimplantation group, basal ring dilatation during the follow-up was limited and similar across the different categories of basal ring size ($P = 0.47$) whereas in the subcommissural annuloplasty group basal ring dilatation during the follow-up increased from small to large basal ring categories ($P = 0.01$). As a result, overall basal ring reduction between pre-repair and follow-up was small and similar between different categories of basal ring size in the subcommissural annuloplasty group ($P = 0.55$) whereas in the valve sparing reimplantation group overall basal ring reduction increased from the small to large categories of basal ring size ($P < 0.001$).

DISCUSSION

As with the mitral valve, the role of annuloplasty is a matter of debate in aortic valve repair. It is known that basal ring size is related to aortic regurgitation severity and that large basal ring left unreduced or insufficiently stabilized during aortic valve repair can favour recurrent aortic regurgitation; this scenario occurs in

Table 4: Echocardiographic measurements of the basal ring diameter

	Preoperative BR (mm)	Postoperative BR (mm)	FU BR (mm)	Difference Pre-Post (mm)	Difference Post-FU (mm)	Difference Pre-FU (mm)	*P*-values[a]
Full cohort							
SCA (*n* = 146)	24 ± 3	19 ± 3	24 ± 4 (*n* = 81)	5 ± 3	4 ± 3	1 ± 2	0.16
VSR (*n* = 154)	27 ± 4	20 ± 3	22 ± 3 (*n* = 85)	7 ± 3	2 ± 2	5 ± 3	<0.001
P-values[b]	<0.001	0.01	0.04	<0.001	<0.001	<0.001	
Subgroup with BR ≤24 mm[c]							
SCA (*n* = 87)	22 ± 1	17 ± 2	21 ± 3 (*n* = 43)	5 ± 2[d]	3 ± 3[e]	1 ± 2[f]	0.02
VSR (*n* = 48)	23 ± 1	18 ± 2	20 ± 1 (*n* = 22)	5 ± 2[d]	2 ± 2[e]	2 ± 2[f]	<0.001
P-values[b]	0.06	0.46	0.06	0.52	0.06	0.02	
Subgroup with BR 25–27 mm[c]							
SCA (*n* = 41)	26 ± 1	21 ± 2	24 ± 2 (*n* = 22)	5 ± 2	4 ± 2	1 ± 2	0.003
VSR (*n* = 43)	26 ± 1	20 ± 2	22 ± 2 (*n* = 25)	6 ± 2	2 ± 2	4 ± 2	<0.001
P-values[b]	0.98	0.14	<0.001	0.13	0.001	<0.001	
Subgroup with BR ≥28 mm[c]							
SCA (*n* = 18)	30 ± 2	23 ± 2	29 ± 3 (*n* = 16)	7 ± 3[d]	6 ± 4[e]	1 ± 2[f]	0.10
VSR (*n* = 63)	30 ± 2	22 ± 2	24 ± 3 (*n* = 38)	9 ± 3[d]	2 ± 2[e]	7 ± 3[f]	<0.001
P-values[b]	0.97	0.12	<0.001	0.14	<0.001	<0.001	

FU: follow-up; SCA: subcommissural annuloplasty; BR: Basal ring diameter; VSR: valve sparing reimplantation.
[a]Compared BR size between preoperative and follow-up periods;
[b]Compared BR size between SCA and VSR groups;
[c]Follow-up length in the SCA group was longer compared with the VSR group in full cohort ($P = 0.01$), BR ≤24 mm subgroup ($P = 0.35$), BR 25–27 mm subgroup ($P = 0.02$) and BR ≥28 mm subgroup ($P = 0.48$).
[d]Compared pre-post differences between BR ≤24 mm and BR ≥28 mm in SCA and VSR, $P < 0.001$.
[e]Compared post-FU differences between BR ≤24 mm and BR ≥28 mm, in SCA, $P = 0.01$, and VSR, $P = 0.47$.
[f]Compared pre-FU differences between patients with BR ≤24 mm and BR ≥28 mm in SCA, $P = 0.49$ and VSR, $P < 0.001$.

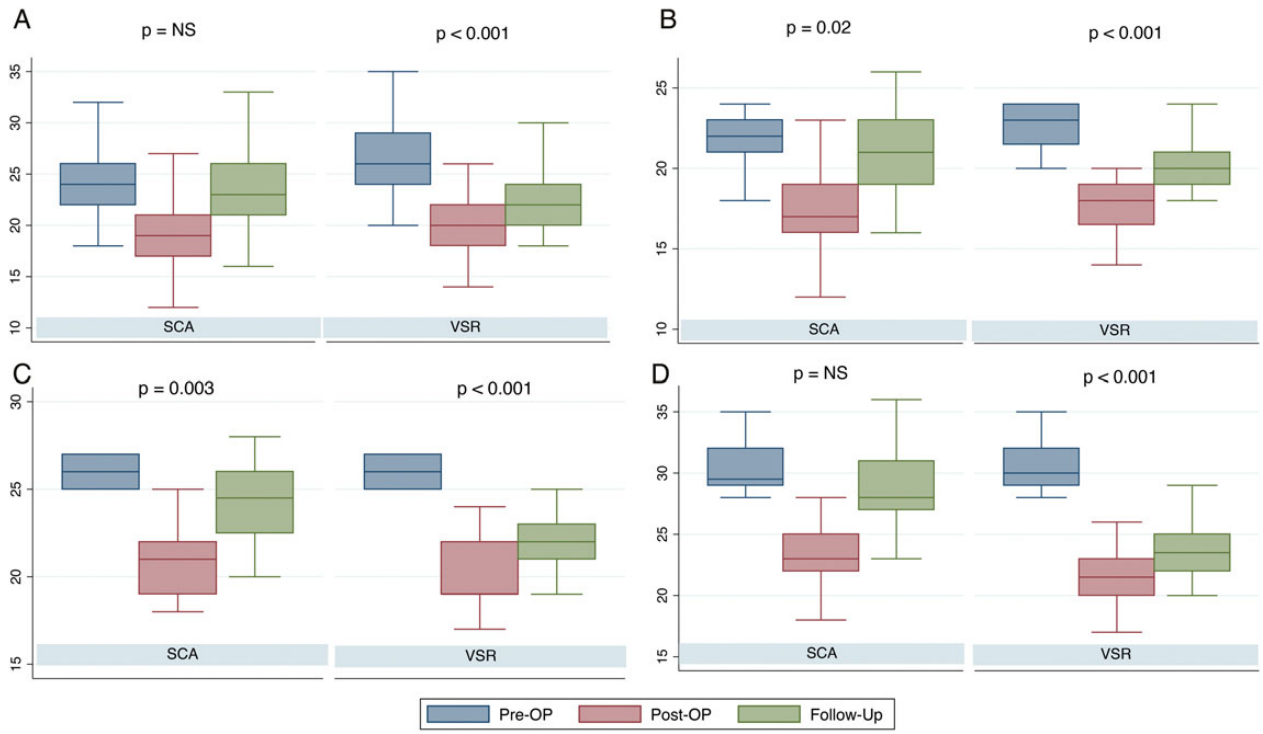

Figure 4: Box plot illustrating variations in BR size between pre-, postoperative and follow-up periods with SCA and VSR; (**A**) in all patients, (**B**) patients with BR <24 mm, (**C**) patients with BR between 25 and 27 mm and (**D**) patients with BR ≥28 mm. *P*-value compares BR size between the preoperative and follow-up period; SCA: subcommissural annuloplasty; BR: basal ring; VSR: valve sparing reimplantation.

aortic valve sparing root replacement with the remodelling technique or in bicuspid aortic valve repair with the subcommissural annuloplasty technique [2, 11–14].

In this study, we showed that in a cohort of tricuspid aortic valve patients selected for aortic valve sparing and repair surgery the mean basal ring size (25 mm) is relatively similar to normal population. Basal ring size was related to patient morphology (body surface area, gender) and disease characteristics (younger age, left ventricular end-diastolic diameter and root size). In general, we were able to achieve good clinical outcomes with all types of repair techniques. In the subcommissural annuloplasty group, patients having preoperative basal ring ≥28 mm presented significantly more recurrent aortic regurgitation compared with those with basal ring <28 mm whereas in the valve sparing reimplantation group basal ring size has no impact on recurrent aortic regurgitation. In a matched comparison of subcommissural annuloplasty and valve sparing reimplantation groups, recurrent aortic regurgitation was more frequent in subcommissural annuloplasty compared with valve sparing reimplantation for patients with basal ring ≥28 mm. Finally, we also showed that the subcommissural annuloplasty technique allows more dilatation of the basal ring over time than the valve sparing reimplantation, which probably explains the higher rate of recurrent aortic regurgitation observed in this group.

Aortic valve repair durability depends mainly on valve-related and technical factors. The valve-related factors include severity of regurgitation, characteristics of cusp disease (i.e. cusp fibrosis, calcification and restriction) and valve geometry (e.g. commissural orientation or large basal ring) [1, 4, 13–17]. The technical factors involved in repair failure include ineffective techniques used for certain types of cusp disease (e.g. thinning, decalcification or patching [4, 15, 16]) or valve geometry (e.g. root remodelling or subcommissural annuloplasty in case of large basal ring [1, 13, 18]). Alternatively, technical factors are also due to inappropriate use of certain techniques of valve repair, leading to suboptimal results (e.g. residual prolapse, short effective height) [14, 15, 19–21]. In line with our studies on the bicuspid aortic valve, we showed that subcommissural annuloplasty was not a durable technique for treating tricuspid aortic valve patients with a large basal ring due to its inability to stabilize the basal ring over time. We also found in this study that small body surface area and large left ventricular end-diastolic diameter are correlated to recurrent aortic regurgitation, which is probably due to smaller body surface area being associated with the subcommissural annuloplasty technique and left ventricular end-diastolic diameter being associated with more severe aortic regurgitation preoperatively.

The basal ring measurements taken at the follow-up demonstrated that the instability of subcommissural annuloplasty over time was evident not only in patients with recurrent aortic regurgitation, but also in most of the patients. During the follow-up, the basal ring seems to dilate within the first years following repair, tending to return to its preoperative dimension. This dilatation occurred due to the tension present in the aortic root wall where the subcommissural annuloplasty sutures were applied. This tension increased proportionally to the diameter of the aortic root, in accordance with Laplace law. Redo surgeries following subcommissural annuloplasty have revealed that the Teflon felt used to reinforce subcommissural annuloplasty sutures can partially migrate into the aortic wall, leading the interleaflet triangle previously closed by the subcommissural annuloplasty to reopen up widely at the level of or below the subcommissural annuloplasty suture. It is worth noting that after valve sparing reimplantation, the basal ring also increased in size during the follow-up, although this was to a lesser extent than that observed after subcommissural annuloplasty. This dilatation corresponded to the 'normal' expansion of a vascular graft in arterial position. In the case of Valsalva grafts, dilatation can be favoured by that the built-in sinus portion is endowed with more expansibility compared with a straight Dacron tube. In our study, we observed no clinical impacts of the discrete basal ring dilatation observed after valve sparing reimplantation.

In this cohort of patients with tricuspid aortic valve, mean preoperative basal ring size (25 ± 4 mm) was smaller than that observed in bicuspid aortic valve patients (28 ± 3 mm) and relatively similar to the one reported in adults with normal tricuspid aortic valve [1, 22]. The relation found between basal ring size and patient characteristics suggests that in tricuspid aortic valve, basal ring size follows a mix of morphological and pathological patterns, while in bicuspid aortic valve, basal ring size appears to follow solely pathological patterns (young age and aortic regurgitation severity) [1]. In the other words, severe basal ring dilatation, considered pathological given its nature of being out of proportion to individual gender or body size, is undeniably more common in bicuspid aortic valve than in tricuspid aortic valve. In the study by Roman *et al*. [22] that focused on normal root dimension, the upper limit of basal ring in normal adults was 31 mm in men and 26 mm in women, with an indexed value of 16 mm/m^2 in both genders. The same upper limit of 31 mm was confirmed in a recent study by Bierbach *et al*. [23]. In our surgical cohorts comprising 75% males, a basal ring of ≥31 mm was found only in men, in 17% of bicuspid aortic valve and 9% of tricuspid aortic valve. An indexed basal ring of ≥16 mm/m^2 was exhibited by 19.5% of bicuspid aortic valve patients and 11% of tricuspid aortic valve.

While there is no doubt regarding the need of basal ring annuloplasty for treating aortic regurgitation in patients with extremely large basal ring (>31 mm), little evidence is available supporting its use in cases of aortic regurgitation with a normal or moderately dilated basal ring [1, 18]. Combining our results with findings in the literature, we would recommend systematically performing stable circumferential annuloplasty in all aortic valve repair cases exhibiting a basal ring size of ≥28 mm on echocardiographic imaging [1, 13, 14, 18]. For patients with normal basal ring, very acceptable long-term durability has been reported with and without annuloplasty [1, 14, 18], and our study confirms this finding. In our experience with aortic valve repair procedures, our policy has been to support the repair almost systematically with an annuloplasty, for the reasons outlined in the methods. Given the relative inefficiency of the subcommissural annuloplasty technique over time, we assume that a certain percentage of patients with normal or subnormal basal ring who received a subcommissural annuloplasty could have exhibited similar outcomes even with no annuloplasty. In patients with a basal ring of <28 mm, the relative impact of basal ring annuloplasty on repair durability is probably less important than that of cusp repair.

In regard to these findings, we deem it necessary to reconsider the role of subcommissural annuloplasty in aortic valve repair. Although this technique offers a simple way of reducing basal ring size and increasing valve coaptation, its effect decreases over time. The residual effect is insufficient in patients with a large basal ring (≥28 mm), yet probably sufficient in those with moderately dilated basal ring. We, therefore, believe that this technique can be still recommended in selected patients with a normal to moderately dilated basal ring (<28 mm) associated with small geometric cusp height or in case of commissural gap.

On the other hand, the valve sparing reimplantation techniques provide an efficient and stable annuloplasty of the basal ring. Except for the 2% incidence of permanent pace maker implantation, the valve sparing reimplantation technique has shown to be safe, and is able to produce excellent clinical results. In the present cohort, 20% of valve sparing reimplantation procedures were performed in patients with an aortic root diameter <45 mm. On the basis of these results, we consider the valve sparing reimplantation an advisable option in experienced hands for treating aortic regurgitation in patients with a large basal ring and none-to-moderate aortic root dilatation. However, further investigation and technical development need to focus on circumferential annuloplasty techniques that preserve normal aortic root, and avoid atrioventricular conduction disturbance.

Study limitations

This was a retrospective study employing surgical techniques for specific indications that evolved during the study period. Despite the relatively large cohort, the prevalence of the variable analysed (basal ring ≥28 mm) was relatively small, which limits the statistical power in subgroup analysis. Patients in the valve sparing reimplantation group presented with the shorter follow-up than that of the subcommissural annuloplasty group. However, it is less probable that a 12-month difference in the mean follow-up observed between the two groups could alone account for the differences observed in basal ring size at the follow-up. The follow-up analysis of the basal ring size was based on one measurement only per patient. Therefore, we could not study the evolution of basal ring size during the follow-up. However, given the significant basal ring dilatation exhibited by several patients within 3 years after surgery, it is likely that basal ring dilatation occurred mainly within the first 2–3 years following surgery, at which point it probably plateaued close to the preoperative size for subcommissural annuloplasty patients, and at a much smaller size for valve sparing reimplantation patients.

Intra- and interobserver variability, more pronounced in transthoracic echocardiography, and off-axis measurements have introduced a non-systematic error into the basal ring diameter assessments. We investigated in this study only one index of basal ring size. Intraoperative measurement by direct intubation was not performed, whereas some authors report it to be more representative of the true basal ring size. Two-dimensional echocardiography generally underestimates basal ring diameter in comparison with direct intubation. In the future, systematic three-dimensional echocardiography should help to provide more accurate sizing of the basal ring, which is generally oval shaped under physiological conditions.

CONCLUSION

In tricuspid aortic valve, a large basal ring is less frequent than in bicuspid aortic valve. However, as is the case in bicuspid aortic valve, a large basal ring size predicts recurrence of aortic regurgitation following repair using the subcommissural annuloplasty technique. The underlying cause is the instability of the subcommissural annuloplasty, with basal ring dilatation occurring during the first years following repair. In patients undergoing the valve sparing reimplantation technique, a large basal ring does not predict recurrent aortic regurgitation due to the prosthetic-based circumferential annuloplasty provided by valve sparing reimplantation proving better stability over time. In consideration of these findings, a stable circumferential annuloplasty is recommended in tricuspid aortic valve repair whenever the patient exhibits a basal ring size ≥28 mm.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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Conflict of interest: none declared.

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APPENDIX: CONFERENCE DISCUSSION

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***Dr H.-J. Schaefers** (Homburg/Saar, Germany):* I completely agree with you, there is increasing evidence that annulus stabilization is important in order to successfully repair aortic valves both bicuspid and tricuspid, and you've previously shown it also for the bicuspid valves.

In this presentation you have very nicely shown that the Cabrol sutures, or subcommissural annuloplasty, which have been used for the past 40 years plus, are apparently not quite effective enough in reducing annulus size and also stabilizing it to the reduced level. This, on the other hand, is very effectively done by valve-sparing root replacement. And I completely agree with your conclusion, with your last conclusion, we need to do something circumferential in order to stabilize the annulus.

The key question, of course, is: What to do? Would you now, based on this experience, recommend primary root replacement irrespective of root size that is, even in the presence of a 35-mm root, or would you simply lower the threshold for root replacement compared to previous recommendations?

The second question is: External versus internal circular annuloplasty, can you maybe give us your personal opinion on which is the way to go.

Dr De Kerchove: First, I would make the distinction between tricuspid and bicuspid valve regarding the root size threshold valve-sparing reimplantation. We would decrease the threshold of valve-sparing in the bicuspids much more, because we have found two main advantages for valve-sparing in the bicuspid valve, one is the possibility to change the valve geometry and, the second is to provide a stable in circumferential annuloplasty of the VAJ. So for bicuspid valve, yes, we have reduced the root size threshold and we do valve-sparing in very normal root if we want to modify the valve geometry. And by making the bicuspid valve symmetrical, we may have a beneficial effect on the durability of the repair.

Now, in the tricuspid valve, the situation is different. Generally the valve has 120 degrees and we very rarely modify this configuration. So I would not lower the threshold of valve-sparing reimplantation unless you have evident sign of root tissue fragility and disease and a large VAJ. We need a new device that can efficiently stabilize the VAJ in the patients with normal root size. And there are several devices already on the market or under investigation, and I think the future will tell us which patients are best indicated in which situation. We are actually using the Simplici-T band that we place around the aortic root as deeply as we can and we fix it with the circumferential proximal suture line like we do in the valve-sparing procedure. That is actually the way we perform such VAJ annuloplasty, let's call it the ring annuloplasty.

Dr Schaefers: I may have missed it. So what millimetres in bicuspid and what millimetres in tricuspid sinus size are your thresholds for root replacements now?

Dr De Kerchove: In the bicuspid valve if we want to change the root geometry, we have no threshold. We may replace very normal root. In the tricuspid valve, I would keep the threshold recommended by the guidelines.

Dr E. Lansac *(Paris, France):* It's very interesting to see that actually as you very clearly demonstrate on bicuspid and tricuspid valve, that there is a need not only to stabilize the aortic annulus but to perform an annuloplasty which is a key component of aortic valve repair now.

My question is: in this tricuspid population, you look at the differences between Cabrol stitches and proximal suture of the reimplantation. But in the subgroup that had Cabrol stitches, did you look at the size of the sinotubular junction, whether a dilated sinotubular junction above 30 or 35 was a risk factor of recurrent AI?

Dr De Kerchove: No, we haven't looked at the sinotubular junction size. We haven't tested it as a predictor of recurrent AI.

As we generally corrected it quite aggressively when it is enlarged with a supracoronary ascending replacement and that was the case in a couple of patients who need it, it is supposed to be normalized after the repair.