Aortic valve cusp repair does not affect durability of modified aortic valve reimplantation for tricuspid aortic valves

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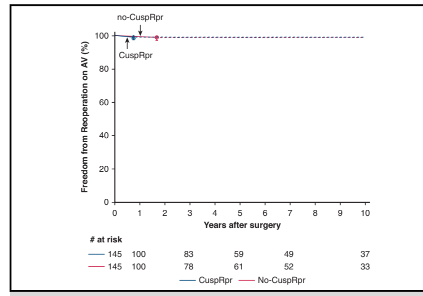
ABSTRACT

Objective: During aortic valve reimplantation, cusp repair may be needed to produce a competent valve. We investigated whether the need for aortic valve cusp repair affects aortic valve reimplantation durability.

Methods: Patients with tricuspid aortic valves who underwent aortic valve reimplantation from January 2002 to January 2020 at a single center were retrospectively analyzed. Propensity matching was used to compare outcomes between patients who did and did not require aortic valve cusp repair.

Results: Cusp repair was performed in 181 of 756 patients (24%). Patients who required cusp repair were more often male, were older, had more aortic valve regurgitation, and less often had connective tissue disease. Patients who underwent cusp repair had longer aortic clamp time (124 ± 43 minutes vs 107 ± 36 minutes, $P = .001$). In-hospital outcomes were similar between groups and with no operative deaths. A total of 98.3% of patients with cusp repair and 99.3% of patients without cusp repair had mild or less aortic regurgitation at discharge. The median follow-up was 3.9 and 3.2 years for the cusp repair and no cusp repair groups, respectively. At 10 years, estimated prevalence of moderate or more aortic regurgitation was 12% for patients with cusp repair and 7.0% for patients without cusp repair ($P = .30$). Mean aortic valve gradients were 6.2 mm Hg and 8.0 mm Hg, respectively ($P = .01$). Ten-year freedom from reoperation was 99% versus 99% ($P = .64$) in the matched cohort and 97% versus 97%, respectively ($P = .30$), in the unmatched cohort. Survival at 10 years was 98% after cusp repair and 93% without cusp repair ($P = .05$).

Conclusions: Aortic valve reimplantation for patients with tricuspid aortic valves has excellent long-term results. Need for aortic valve cusp repair does not affect long-term outcomes and should not deter surgeons from performing valve-sparing surgery. (JTCVS Open 2023;16:105-22)



Need for reoperation by need for cusp repair at the time of aortic valve reimplantation.

CENTRAL MESSAGE

The need for cusp repair at the time of aortic valve reimplantation does not affect long-term hemodynamic or clinical outcomes and should not deter surgeons from performing a valve-sparing operation.

PERSPECTIVE

Cusp repair is often needed during aortic valve reimplantation to achieve a competent valve. This study demonstrates that cusp repair does not affect long-term outcomes and should be performed when indicated at the time of reimplantation to achieve a competent aortic valve.

Video clip is available online.

Valve-sparing aortic root replacement with aortic valve reimplantation is a well-established treatment for patients with aortic root aneurysms and select patients with aortic valve regurgitation.[1-4] For patients with tricuspid aortic valves and aortic regurgitation (AR) due to dilatation of the aortic

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Abbreviations and Acronyms

AR	= aortic regurgitation
BSA	= body surface area
LV	= left ventricular
TAVR	= transcatheter aortic valve replacement

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anulus, sinuses, or sinutubular junction, reimplantation alone generally restores valve competence.[5] In other patients, intrinsic valvular abnormalities, including fenestrations and cusp prolapse, may contribute to AR. In these cases, cusp repair techniques, including leading-edge commissuroplasty with figure-of-8 suture, cusp plication, and closure of fenestrations, may be used to achieve a competent valve.[6]

Early outcomes after aortic valve reimplantation, with or without cusp repair, are excellent.[3,7] However, whether the need for cusp repair affects the durability of aortic valve reimplantation remains the subject of active research.[8-11] One could hypothesize that the need for cusp repair would portend worse durability, either due to the effect of suture material on cusp fibrosis or the underlying substrate that produced cusp abnormalities in the first place. Alternatively, by eliminating residual aortic valve regurgitation, cusp repair techniques could enhance durability. We sought to understand whether the need for aortic valve cusp repair affects the durability of aortic valve reimplantation.

PATIENTS AND METHODS

Patients and Data

From January 2002 to January 2020, 756 consecutive patients with tricuspid aortic valves underwent valve-sparing aortic root replacement with aortic valve reimplantation at the Cleveland Clinic. The primary indication for valve-sparing aortic root replacement was inferred from baseline aortic dimensions and degree of AR. Patients with less than severe AR were considered to have aortic root dilatation as the primary indication. Patients with severe AR and maximum aortic diameter less than 4.5 cm were considered to have AR as the primary indication. Patients with severe AR and maximum aortic diameter 4.5 cm or greater were considered to have co-primary indications. For patients with AR, assessment of repairability and choice of repair techniques were made by the surgeon in the operating room. Cusp repair was performed in 181 of 756 patients (24%) (Figure 1). The number of patients with concomitant cusp repair increased slightly over the study time period (Figure E1).

Patient baseline characteristics are summarized in Table 1. Compared with patients with tricuspid aortic valves who received reimplantation without cusp repair, patients who had cusp repair were more often male (90% vs 79%), were older (54 ± 13 vs 49 ± 14 years), had more aortic valve regurgitation (80% vs 55%), less often had connective tissue disease (19% vs 31%), had larger LV end-diastolic volume index (69 ± 23 vs 63 ± 22 years) and systolic volume index (25 ± 11 vs 23 ± 10 years), had larger LV mass index (126 ± 45 vs 111 ± 38 years), and had larger mid-ascending aorta diameter (4.5 ± 0.75 vs 4.4 ± 0.83 years).

Surgical Techniques

Valve-sparing aortic root replacement with aortic valve reimplantation was performed as previously described (Figure 2 and Video 1).[7,12,13] The left ventricular (LV) outflow tract diameter was routinely reduced to an appropriate size for body surface area (BSA) by tying pledgeted subanular sutures over a Hegar dilator. Hegar dilator size is chosen according to BSA and patient sex as follows: 23 mm for BSA of 2.0 to 2.5 m^2, 21 mm for BSA 1.5 to 2.0 m^2, and 19 mm for BSA less than 1.5 m^2 for men and sometimes smaller for women.[12,13]

Cusp repair was performed in 181 of 756 patients (24%). Repair techniques included leading-edge commissuroplasty with figure-of-8 suspension suture (83%), cusp plication (23%), closure of fenestrations (8.3%), cusp debridement (6.6%), bicuspidization (2.2%), subcommissural closure (1.7%), and cusp resection (0.55%) (Table 2).

Data

Baseline, procedural, and morbidity data were abstracted prospectively for quality reporting by independent registry nurses and entered into the Cardiovascular Information Registry. Transthoracic echocardiographic data were measured and entered into the Echocardiography Database by clinical echosonographers. Other Cleveland Clinic electronic medical record databases were also queried. All data used for this study were approved for use in research by the Cleveland Clinic Institutional Review Board, with patient consent waived (IRB #4826, approved on December 8, 2021 for the period of December 28, 2021-December 27, 2022).

End Points

Operative morbidities and mortality. Operative mortality and major morbidities were defined as for the Society of Thoracic Surgeons National database.[14]

Longitudinal echocardiographic outcomes. For longitudinal estimation of aortic valve regurgitation, mean gradient, and LV mass regression, all transthoracic echocardiograms performed at the Cleveland Clinic or provided to the clinic from elsewhere were reviewed, and the results were stored in the echocardiography database. We extracted from that database the grade of aortic valve regurgitation ascertained by measuring jet width in the LV outflow tract with color Doppler, jet deceleration rate with continuous-wave Doppler, presence of diastolic flow reversal in the descending aorta, vena contracta width, jet width/LV outflow tract width ratio, and regurgitant volume and fraction. AR was graded according to a semiquantitative scale as none or trace, mild, moderate, or severe. There were 658 echocardiogram records available for 178 of 181 patients (98%) in the cusp repair group and 1855 echocardiogram records for 559 of 575 patients (97%) in the no-cusp repair group (Figure E2). All longitudinal measurements were censored at the time of reoperation.

Time-related aortic valve reoperation and mortality. Cross-sectional follow-up was used to assess reoperations on the aortic valve and vital status via mailed questionnaire or telephone contact with the patient or a family member. The median follow-up of the cusp repair cohort was 3.9 years, with 25% followed more than 10 years and 10% followed more than 15 years. The median follow-up of the no-cusp repair cohort was 3.2 years, with 25% followed more than 7.2 years and 10% followed more than 11 years. Cross-sectional follow-up for vital status was supplemented with Social Security Death Master File (to 2011) and Ohio State Death Registry data. Median follow-up for vital status in the cusp repair cohort was 5 years, with 25% followed more than 12 years and 10% followed more than 15 years. Median follow-up for vital status in the no-cusp repair cohort was 4.6 years, with 25% followed more than 8.9 years and 10% followed more than 13.6 years.

Statistical analysis. Statistical analyses were performed with SAS version 9.4 (SAS Institute, Inc) and R version 3.6.0 (R Foundation for Statistical Computing). Continuous variables are summarized as mean ± standard deviation or as equivalent 15th, 50th (median), and

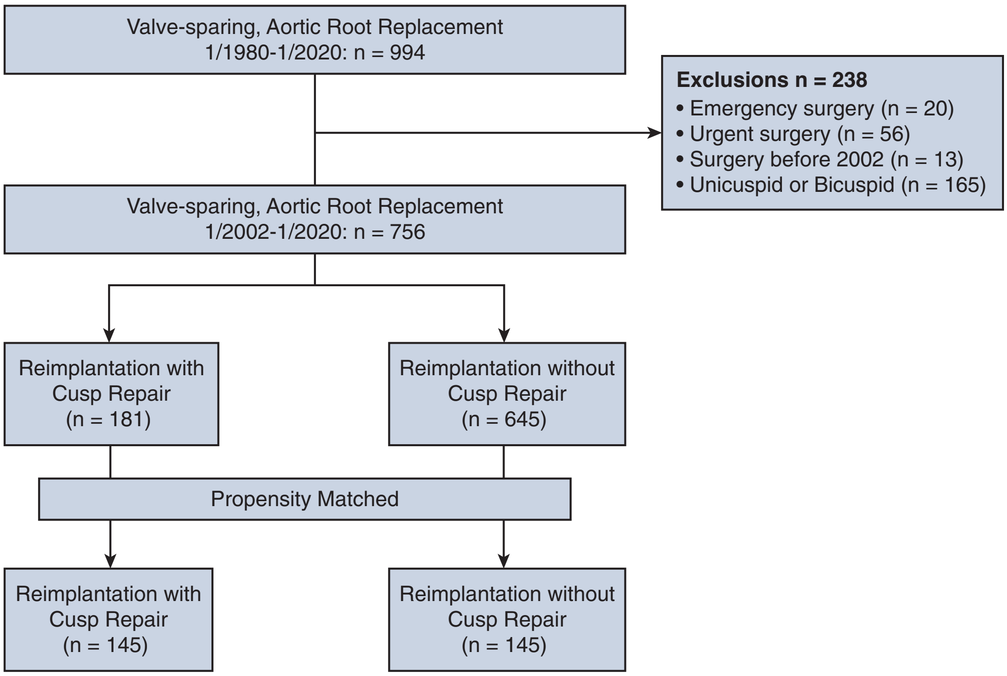


FIGURE 1. CONSORT-style diagram of patients undergoing tricuspid aortic valve–sparing root replacement with or without cusp repair.

85th percentiles when distribution of values was skewed. Categorical data are summarized by frequencies and percentages. Differences between the preoperative characteristics of the cusp repair and no-cusp repair groups are expressed as standardized mean differences (%). Comparison of continuous outcomes was determined with the Wilcoxon rank-sum test, and categorical outcomes were determined with the chi-square test or Fisher exact test as appropriate. Confidence intervals for longitudinal estimates used a bootstrap percentile method to obtain 68% confidence bands (equivalent to ±1 standard error) and the delta method for time-related events. A type I error of 0.05 was used to assess statistical significance.

Propensity score rationale, development, and matching.

Rationale. There were a number of differences in patient and procedure variables (Table 1) between the 2 cohorts. We used propensity score matching to reduce bias between the cusp repair and no-cusp repair groups for comparison of outcomes.

Missing values. In this analysis, a number of variables had missing values. We used 5-fold multiple imputation[15] using multivariate imputation by chained equations. A parsimonious logistic regression model for distinguishing patients in the cusp repair group from those in the no-cusp repair group was then developed using the first imputation data set. For this, variable selection from those listed in Appendix E1 used bagging[16] with a *P* value criterion for retention of variables in the model of .05, based on automated analysis of 1000 bootstrap data sets (C-statistic = .69) (Table E1). Regression coefficients and their variance-covariance matrix were estimated for each of the 5 models, which were then combined to yield final regression coefficient estimates, the variance–covariance matrix, and *P* values.[15]

Propensity score development. A propensity score model was developed by adding nonsignificant variables to the parsimonious model representing patient demographics, symptoms, and cardiac and noncardiac comorbidity variables that might be related to unrecorded factors (saturated model with 33 variables, C-statistic = .79). The propensity score for each patient was obtained by averaging 5 propensity scores calculated from 5 saturated models based on the imputed data sets.[17]

Matching. By using only the propensity score, cusp repair cases were matched 1:1 to no-cusp repair cases using a greedy matching strategy[18] in the logit domain with a caliper width equal to 0.2 times the standard deviation of the logit of the propensity score,[19] yielding 145 well-matched patient pairs (80% of the cusp repair study cohort, Figure E3). An absolute value of standard mean difference 10% or less is usually interpreted as acceptable matching.[20]

Echocardiographic longitudinal data analyses. To assess the temporal trend of individual grades of postoperative AR (ordinal longitudinal data), follow-up transthoracic echocardiograms were analyzed longitudinally for pattern of change across time using a nonlinear multiphase mixed-effects cumulative logit regression model.[21] Prevalence of each AR grade over time was estimated by averaging patient-specific profiles. Note that because there were few echocardiogram records with severe grades, severe grade category was collapsed together with moderate grade category. A multiphase nonlinear mixed-effects regression model was used to similarly estimate the temporal ensemble average of postoperative mean gradient and aortic root diameter (continuous longitudinal data).[22]

Time-related analyses. Survival and freedom from aortic valve reoperation were estimated nonparametrically by the Kaplan–Meier method and compared using log-rank test. These were accompanied with 68% confidence bars equivalent to ±1 standard error. For a sensitivity analysis, we used inverse probability treatment weighting with stabilized weights[23] in Cox PH regression to compare the time to events using the entire cohort.

RESULTS

Intraoperative, In-Hospital Morbidities, and Operative Mortality

In the matched cohorts, compared with patients who underwent reimplantation without cusp repair, patients with cusp repair had longer cardiopulmonary bypass (median [15th, 85th percentile]: 139 [101, 208] vs 125 [85, 165] minutes, $P < .001$) and myocardial ischemia times (116 [81, 176] minutes vs 105 [71, 141] minutes, $P = .001$) (Table 2). In-hospital outcomes, including transfusion, length of stay, and operative mortality, were similar between the groups (Table 3).

TABLE 1. Baseline characteristics of patients undergoing tricuspid aortic valve–sparing root replacement with or without cusp repair: Original and propensity-matched cohorts

	Original cohorts					Propensity-matched cohorts				
	Cusp repair (n = 181)			No cusp repair (n = 575)		Cusp repair (n = 145)			No cusp repair (n = 145)	
Characteristics	n*	No. (%) or mean ± SD	Standard difference (%)	n*	No. (%) or mean ± SD	n*	No. (%) or mean ± SD	Standard difference (%)	n*	No. (%) or mean ± SD
Demographics										
Age (y)	181	54 ± 13	36	575	49 ± 14	145	52 ± 14	−1.6	145	52 ± 13
Female	181	19 (10)	−29	575	121 (21)	145	17 (12)	−12	145	23 (16)
Height (cm)	179	181 ± 9.1	−1.4	571	181 ± 10	144	181 ± 9.1	−0.96	143	181 ± 9.7
BMI	179	28 ± 4.9	0.19	571	28 ± 5.6	144	28 ± 5	1.4	143	28 ± 5.2
Race: White	181	164 (91)	2.2	558	502 (90)	145	131 (90)	13	139	120 (86)
Primary indication										
Aortic root dilatation	181	136 (75)	−38	575	514 (89)	145	120 (83)	3.6	145	118 (81)
AR	181	20 (11)	29	575	20 (3.5)	145	9 (6.2)	0.0	145	9 (6.2)
Co-primary (dilatation and AR)	181	25 (14)	22	575	41 (7.1)	145	16 (11)	−4.3	145	18 (12)
Valve pathology										
AR grade	179		63	560		144		−11	143	
None/trace		34 (19)			246 (44)		34 (24)			30 (21)
Mild		35 (20)			117 (21)		35 (24)			29 (20)
Moderate		65 (36)			136 (24)		50 (35)			57 (40)
Severe		45 (25)			61 (11)		25 (17)			27 (19)
Connective tissue disorder	181	35 (19)	−27	575	178 (31)	145	33 (23)	−9.6	145	39 (27)
Mitral regurgitation	179	53 (30)	13	559	134 (24)	144	46 (32)	0.54	142	45 (32)
Tricuspid regurgitation	180	36 (20)	5.5	566	101 (18)	145	28 (19)	−11	145	35 (24)
LV function										
Prior myocardial infarction	181	7 (3.9)	−1.6	574	24 (4.2)	145	4 (2.8)	9.7	145	2 (1.4)
Etiology										
Aortic valve: degenerative	159	12 (7.5)	−19	487	49 (10)	145	9 (6.2)	−0.72	141	9 (6.4)
Cardiac comorbidity										
Atrial fibrillation/flutter	175	13 (7.4)	−3.5	561	47 (8.4)	141	12 (8.5)	−5.1	140	14 (10)
Prior cardiovascular surgery	181	18 (9.9)	−6.6	575	69 (12)	145	16 (11)	4.5	145	14 (9.7)
Prior congestive heart failure	181	31 (17)	14	575	71 (12)	145	18 (12)	−2.1	145	19 (13)
Aortic root dimension										
Aortic root diameter (cm)†	171	4.8 ± 0.57	11	545	4.7 ± 0.55	139	4.8 ± 0.58	15	136	4.7 ± 0.58

(Continued)

TABLE 1. Continued

	Original cohorts					Propensity-matched cohorts				
	Cusp repair (n = 181)			No cusp repair (n = 575)		Cusp repair (n = 145)			No cusp repair (n = 145)	
Characteristics	n*	No. (%) or mean ± SD	Standard difference (%)	n*	No. (%) or mean ± SD	n*	No. (%) or mean ± SD	Standard difference (%)	n*	No. (%) or mean ± SD
Aortic root area/height (cm^2/m)	169	10 ± 2.4	11	542	9.8 ± 2.2	138	10 ± 2.5	13	134	9.8 ± 2.4
Mid-ascending diameter (cm)	166	4.5 ± 0.75	20	505	4.4 ± 0.83	135	4.5 ± 0.79	7.6	136	4.4 ± 0.78
Left heart morphology and function										
LVEDVi (mL/m^2)	164	69 ± 23	30	511	63 ± 22	134	67 ± 22	8.6	135	65 ± 21
LVESVi (mL/m^2)	161	25 ± 11	18	504	23 ± 10	132	24 ± 11	6.6	134	23 ± 11
LV mass index (g/m^2)	163	126 ± 45	35	511	111 ± 38	135	116 ± 39	8.0	133	120 ± 43
LV ejection fraction (%)	181	58 ± 5.2	−15	565	59 ± 6.4	145	58 ± 5.2	−5.2	143	59 ± 4.9
Noncardiac comorbidity										
Prior peripheral arterial disease	181	7 (3.9)	−12	575	38 (6.6)	145	7 (4.8)	0.0	145	7 (4.8)
Prior hypertension	181	128 (71)	11	574	376 (66)	145	99 (68)	7.3	145	94 (65)
Pharmacologically treated diabetes	181	6 (3.3)	−0.10	570	19 (3.3)	145	6 (4.1)	0.0	145	6 (4.1)
COPD	181	15 (8.3)	−16	575	76 (13)	145	14 (9.7)	4.8	145	12 (8.3)
Smoking	181	77 (43)	5.0	574	230 (40)	145	59 (41)	4.2	145	56 (39)
Dyslipidemia	181	98 (54)	14	574	271 (47)	145	77 (53)	−4.2	145	80 (55)
Creatinine (mg/dL)	181	0.98 ± 0.19	0.0	575	0.98 ± 0.32	145	0.97 ± 0.18	5.0	145	0.96 ± 0.22
Blood urea nitrogen (mg/dL)	181	17 ± 4.6	23	575	16 ± 5.26	145	16 ± 4.5	−4.3	145	17 ± 4.3
Bilirubin (mg/dL)	179	0.66 ± 0.32	6.0	550	0.64 ± 0.35	145	0.65 ± 0.33	9.5	139	0.62 ± 0.3
Hematocrit (%)	181	43 ± 4.0	7.0	575	43 ± 4.0	145	43 ± 4.1	9.2	145	42 ± 3.9

BMI, Body mass index; *AR*, aortic regurgitation; *LV*, left ventricle; *LVEDVi*, left ventricular end-diastolic volume; *LVESVi*, left ventricular end-systolic volume; *COPD*, chronic obstructive pulmonary disease. *Patients with data available. †Not included in the propensity model.

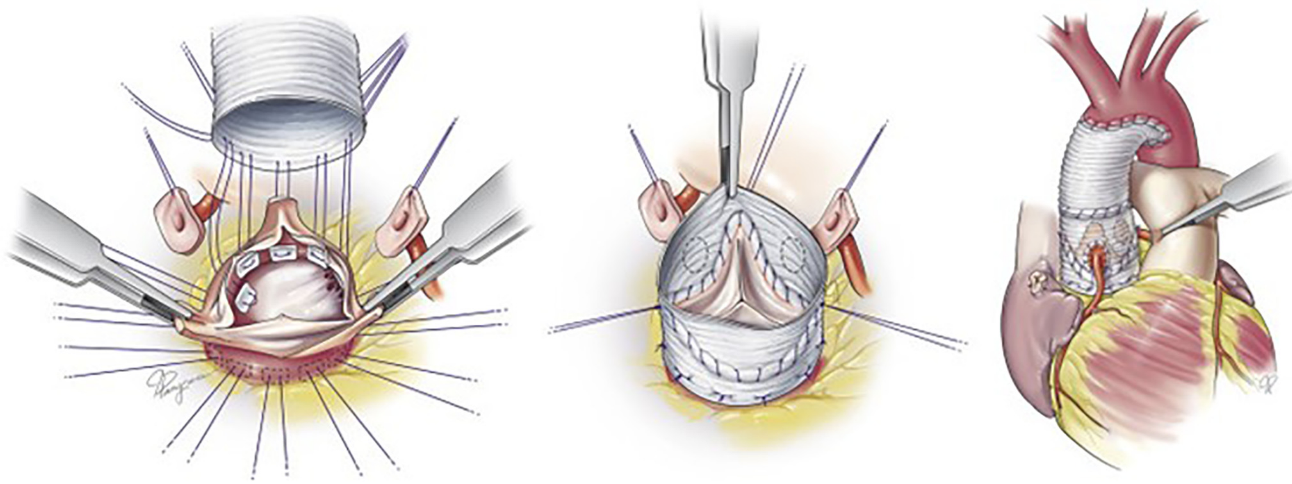


FIGURE 2. Steps in modified reimplantation with pledgeted sutures, a Hegar dilator for normal BSA annular size (not shown), and completion of reimplantation/repair. Reproduced with permission from Svensson LG.[6]

Longitudinal Aortic Valve Hemodynamic Trends

In the matched cohort, there was no significant difference in the prevalence of moderate or more AR between groups at any time point. Estimated prevalence of moderate or more AR at 1, 5, and 10 years was 6.4%, 10%, and 12% for patients with cusp repair and 3.5%, 7.5%, and 7.0% for patients without cusp repair, respectively (Figure 3, *A*; $P = .30$). In the matched cohort, patients without cusp repair had a slightly higher mean aortic valve gradient. Estimate of mean aortic valve gradient at 10 years was 6.2 mm Hg with cusp repair and 8.0 mm Hg without cusp repair (Figure 3, *B*; $P = .01$), but the mean gradient remained less than 10 mm Hg in both groups.

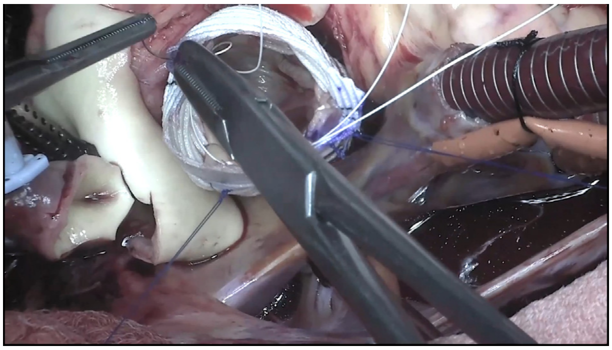
Time-Related Reoperation

In the unmatched population, there were 15 first reoperations for aortic valve pathology observed during follow-up (6 in the reimplantation with cusp repair group and 9 in the reimplantation without cusp repair group). Indication for reoperation was mainly due to AR (5 of 6 in the reimplantation with cusp repair group; 6 of 9 in the reimplantation without cusp repair group) (Table 4).

In the matched cohort, 10-year freedom from reoperation was 99.0% to 99% in the with cusp repair group and without cusp repair group, respectively. There was no significant difference in the risk of reoperation between the 2 matched groups (P[log-rank] = .64, Figure 4). Note that comparison analysis using inverse probability treatment weighting yielded a similar conclusion ($P = .94$).

Survival

There were 32 deaths observed during follow-up (26 in the reimplantation without cusp repair group and 6 in the reimplantation with cusp repair group). In the matched cohort, risk of death was significantly higher in patients without cusp repair than in patients with cusp repair (*P* [log-rank] = .05, Figure 5). Survival at 10 years was 98% after cusp repair and 93% without cusp repair in the matched cohorts. Note that comparison analysis using inverse probability treatment weighting yielded similar conclusions ($P = .05$).



VIDEO 1. Surgical technique of figure-of-8 commissure realignment suture in a patient undergoing valve-sparing aortic root replacement with aortic valve reimplantation. Video available at: https://www.jtcvs.org/article/S2666-2736(23)00192-4/fulltext.

DISCUSSION

Principal Findings

After accounting for differences in baseline characteristics, including preoperative degree of AR, there was no difference in progression of AR between patients who did or did not require aortic valve cusp repair at the time of reimplantation. Patients without cusp repair had statistically higher mean gradients, but these remained less than 10 mm Hg in both groups and were not clinically important. Freedom from reoperation was excellent in both groups and not statistically different.

TABLE 2. Concomitant procedures, valve procedures, and operative support of patients undergoing tricuspid aortic valve–sparing root replacement with or without cusp repair: Original and propensity-matched cohorts

	Original cohorts					Propensity-matched cohorts				
	Cusp repair (n = 181)			No cusp repair (n = 575)		Cusp repair (n = 145)			No cusp repair (n = 145)	
Variables	n*	No. (%) or 15th/50th/85th percentiles	Standard difference (%)	n*	No. (%) or 15th/50th/85th percentiles	n*	No. (%) or 15th/50th/85th percentiles	Standard difference (%)	n*	No. (%) or 15th/50th/85th percentiles
Concomitant procedures										
Coronary artery bypass graft	181	16 (8.8)	8.4	575	38 (6.6)	145	8 (5.5)	−2.9	145	9 (6.2)
Mitral valve repair	181	13 (7.2)	−7.4	575	53 (9.2)	145	12 (8.3)	2.6	145	11 (7.6)
AV cusp repair procedures										
Commissuroplasty	181	151 (83)								
Cusp plication	181	42 (23)								
Subcommissural closure	181	3 (1.7)								
Direct closure of perforated fenestration	181	15 (8.3)								
Cusp debridement	181	12 (6.6)								
Cusp resection	181	1 (0.55)								
Bicuspidization	181	4 (2.2)								
Operative support										
Aortic clamp time (min)	181	83/119/175	—	575	68/101/149	145	81/116/176	—	145	71/105/141
CPB time (min)	181	101/142/207	—	575	82/120/172	145	101/139/208	—	145	85/125/165

AV, Aortic valve; *CPB*, cardiopulmonary bypass. *Patients with data available.

TABLE 3. In-hospital outcomes of patients undergoing tricuspid aortic valve–sparing root replacement with or without cusp repair: Original and propensity-matched cohorts

	Original cohorts				Propensity-matched cohorts				
	Cusp repair (n = 181)		No cusp repair (n = 575)		Cusp repair (n = 145)		No cusp repair (n=145)		
Outcomes	**n†**	**No. (%) or 15th/50th/85th percentiles**	**n†**	**No. (%) or 15th/50th/85th percentiles**	**n†**	**No. (%) or 15th/50th/85th percentiles**	**n†**	**No. (%) or 15th/50th/85th percentiles**	***P****
Operative mortality	181	0 (0)	575	0 (0)	145	0 (0)	145	0 (0)	>.9
Permanent stroke	181	5 (2.8)	575	3 (0.52)	145	4 (2.8)	145	1 (0.69)	.18
Deep sternal wound infection	181	0 (0)	570	1 (0.18)	145	0 (0)	143	0 (0)	>.9
Septicemia	181	1 (0.55)	575	2 (0.35)	145	1 (0.69)	145	1 (0.69)	>.9
Reoperation for bleeding or tamponade	181	2 (1.1)	575	9 (1.6)	145	1 (0.69)	145	4 (2.8)	.18
Blood product transfusion	181	83 (46)	575	285 (50)	145	64 (44)	145	68 (47)	.64
New requirement for dialysis	163	2 (1.2)	538	2 (0.37)	130	2 (1.5)	133	1 (0.75)	.55
Prolonged ventilation (>24 h)	180	9 (5)	578	26 (4.5)	144	8 (5.6)	144	10 (6.9)	.63
New postoperative atrial fibrillation	162	67 (41)	514	136 (26)	129	47 (36)	126	41 (33)	.51
Permanent pacemaker	179	0 (0)	570	9 (1.6)	144	0 (0)	143	1 (0.7)	.31
Intensive care unit length of stay (h)	181	22.9/46/87	574	23/41.9/83.5	145	23/46/92.2	145	23/30/94	.39
Postoperative length of stay (d)	181	5/6/9	575	5/6/9	145	5/6/9.1	145	5/6/10	.053

**P* relates to comparison of matched groups. †Patients with data available.

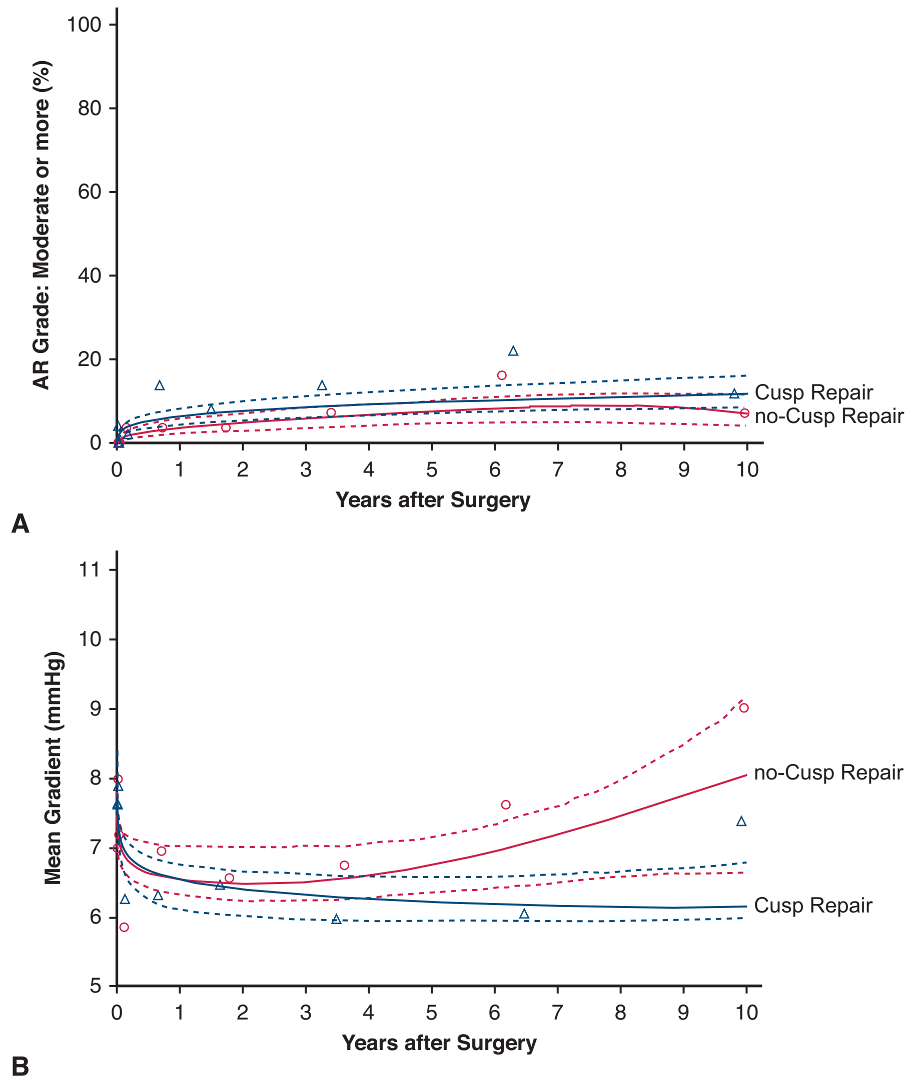


FIGURE 3. Comparison of longitudinal echocardiographic outcomes after tricuspid aortic valve–sparing root replacement with or without cusp repair in the matched cohorts. Symbols represent data grouped (without regard to repeated measurements) within time frames to provide a crude verification of model fit. A, Postoperative prevalence of AR grades. Solid lines represent longitudinal trend in AR grades. B, Temporal trend of postoperative aortic valve mean gradient. Solid line represents unadjusted estimates of temporal trend of postoperative aortic valve mean gradient enclosed within a 68% confidence band. *AR*, Aortic regurgitation.

There was no difference in late survival in the unmatched groups, but after matching it appeared that patients who did not undergo cusp repair group were at increased risk for death over time. Given the similar hemodynamic outcomes between the groups, it is unlikely that these differences are directly related to the need for aortic valve cusp repair at the time of reimplantation. This may be an area for future investigation.

TABLE 4. Indications for reoperation after tricuspid aortic valve–sparing root replacement with or without cusp repair in the original cohorts

Indication	Cusp repair (n = 6) No. (%)	No cusp repair (n = 9) No. (%)
AR	5 (83)	6 (67)
Aortic stenosis	1 (17)	0 (0)
Endocarditis	0 (0)	2 (22)
Pseudoaneurysm	0 (0)	1 (11)

AR, Aortic regurgitation.

These findings reinforce those of other multicenter and large single-center studies on this topic. Especially with technically complex operations such as valve-sparing aortic root replacement with aortic valve cusp repair,[8-11] there can be concerns about the generalizability of outcomes achieved by experts. That multiple centers also have found that cusp repair does not affect durability of valve-sparing aortic root replacement suggests that the findings are generalizable, at least to high-volume aortic centers.

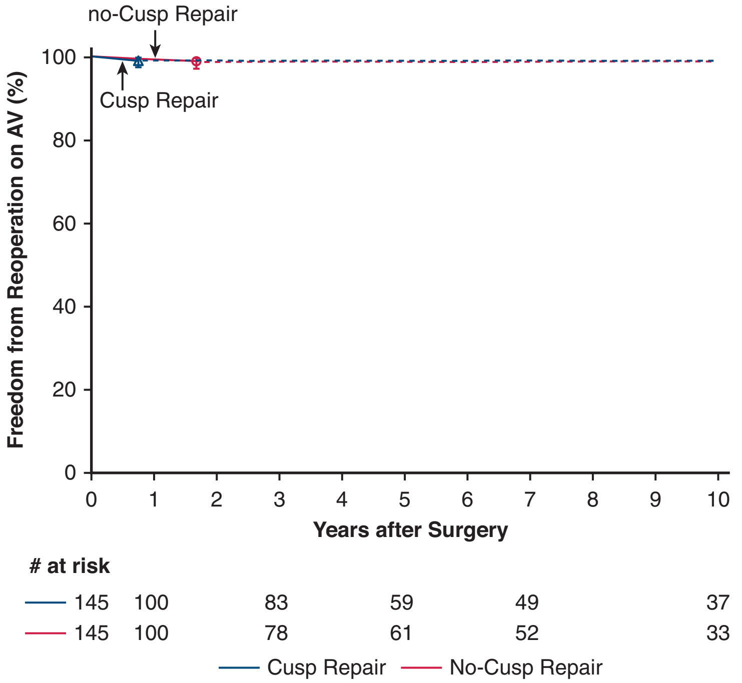


FIGURE 4. Freedom from aortic valve reoperation after tricuspid aortic valve–sparing root replacement with or without cusp repair in the matched cohorts. Each symbol represents a Kaplan–Meier estimate of the event, and vertical bars are 68% confidence limits equivalent to ±1 standard error. Numbers below horizontal axis are patients remaining at risk. *AV*, Aortic valve.

Technical Consideration

Repair of tricuspid aortic valves is complex and often requires multiple repair techniques. We use the commissure, leaflets [cusps], anulus, sinus, sinutubular junction (CLASS) framework for assessing aortic valves.[24-26]

Valve-sparing root replacement with aortic valve reimplantation addresses dilatation of the anulus, sinuses, and sinutubular junction. In our practice, the choice of a straight or Valsalva graft is decided by the surgeon. In either case, the graft is tied over a Hegar dilator with pledgeted subanular

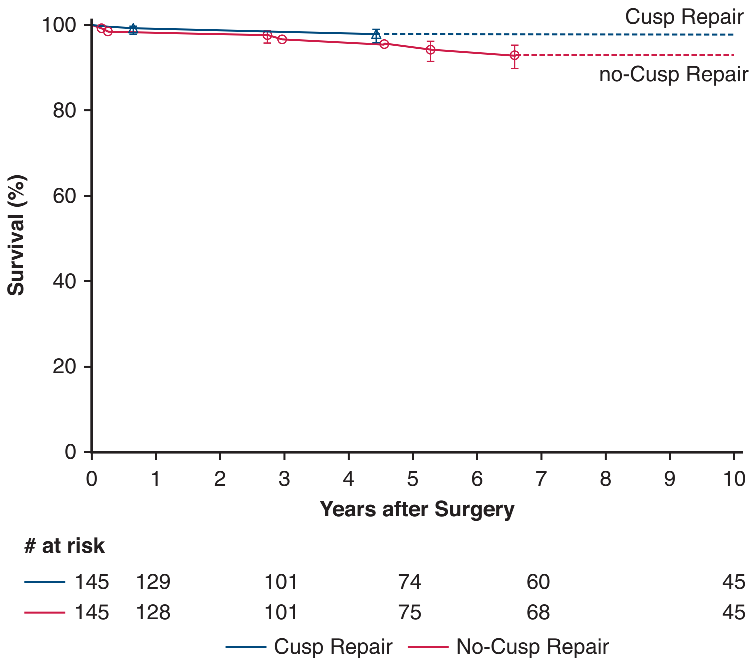


FIGURE 5. Survival after tricuspid aortic valve–sparing root replacement with or without cusp repair in the matched cohorts. Each symbol represents a Kaplan–Meier estimate of the event, and vertical bars are 68% confidence limits equivalent to ±1 standard error. Numbers below horizontal axis are patients remaining at risk.

sutures to reduce the diameter of the LV outflow tract to the appropriate size.

The aortic valve commissures rarely need to be addressed independently during reimplantation. When the base of the cusp is sewn to the graft, care should be taken to make the sub-commissure triangle as narrow as possible. Failure to do so can lead to splaying of the commissure and resultant AR. In these situations, sub-commissural closure can restore valve competence.

The most common mechanism of AR related to cusp function is prolapse. In most cases, this can be addressed with a figure-of-8 suspension stitch to realign the 2 free edges at the top of the commissure, which is brought through the graft approximately 3 to 4 mm above the commissure to hitch it up at a higher level.[27] When there is redundancy of the free edge of a cusp despite supra-commissural realignment and the cusps are of good tissue quality, central plication may be indicated to achieve symmetry of the cusps.

Generally, we consider multiple large fenestrations to be a contraindication to a valve-sparing operation. However, in select cases, fenestrations can be closed with fine polypropylene sutures with excellent results. Besides large fenestrations, features that typically preclude a successful repair are more than minimal cusp calcification or fibrosis.

Phenotypic Associations With Cusp Repair

Patients who required cusp repair had more AR, were older, were less likely to have connective tissue disease, and had more diffuse aortic dilatation beyond the aortic root. These findings suggest 2 distinct phenotypes. One is characterized by age-related dilatation of the ascending aorta and root along with more "wear and tear" of the aortic valve cups. The other is characterized by younger patients with root-predominant aortic dilatation and relatively normal cusps, often in association with connective tissue disease or hereditary thoracic aortic conditions. In the second group, when AR is present, it is caused primarily by dilatation of the aortic root and sinutubular junction rather than abnormalities of the valve cusps themselves.

In related work, our data suggest that after reimplantation, patients with connective tissue disease have slightly better long-term freedom from reoperation at 10 years compared with patients without connective tissue disease.[28] Although this seems counterintuitive, patients with connective tissue disease are typically identified earlier in the course of the disease and treated more proactively than those without. The presence of connective tissue disease, patient-specific root morphology, and need for additional aortic valve repair should all be considered when planning a reoperation procedure.

Aortic Valve Repair in the Era of Transcatheter Valve Replacement

The development of transcatheter aortic valve replacement (TAVR) has led to a paradigm shift in the management of aortic valve disease.[29-31] TAVR is well established for patients with native aortic valve stenosis and for bioprosthetic valve failure (ie, valve-in-valve). However, there are currently no established transcatheter options for patients with native aortic valve regurgitation. Historically, valve repair has been the procedure of choice for these patients, with the goal of achieving durability that is better than a bioprosthetic valve without the need for anticoagulation.[27]

For certain patients with AR, for instance, those with bicuspid aortic valves, concerns about future transcatheter valve options may convince some surgeons to perform valve replacement. However, this line of reasoning should not be applied to patients with tricuspid aortic valves who are candidates for reimplantation with valve repair. In these patients, our data suggest that valve-sparing aortic root replacement with aortic valve reimplantation has excellent long-term durability, even when cusp repair is required. Moreover, there is growing experience with TAVR after valve-sparing aortic root replacement at other institutions, so this approach does not burn any transcatheter bridges.[32] Indeed, our technique of reducing the anulus around a Hegar dilator and the external support provided by the graft creates an ideal landing zone for TAVR. Reimplantation also keeps the coronary ostia high and avoids the potential for coronary obstruction after transcatheter valve deployment. The combination of aortic pure regurgitation and anular dilatation has been associated with reduced durability of the Ross procedure.[33,34] For this reason, valve-sparing aortic root replacement with aortic valve reimplantation should remain the procedure of choice whenever feasible. The need for aortic valve cusp repair should not dissuade surgeons from performing a valve-sparing operation.

Study Limitations

This is a single-center report with most of the procedures performed by a few highly experienced surgeons. The decision to proceed with valve-sparing aortic root replacement and aortic valve reimplantation with cusp repair was based on intraoperative assessment and the surgeon's judgment. This may limit the generalizability of these results. Echocardiographic data were limited in part because our patients were geographically dispersed. Although the results of balancing were excellent, this retrospective study is susceptible to all the limitations and biases that are inherent to retrospective studies.

CONCLUSIONS

Valve-sparing aortic root replacement with aortic valve reimplantation continues to be the procedure of choice for

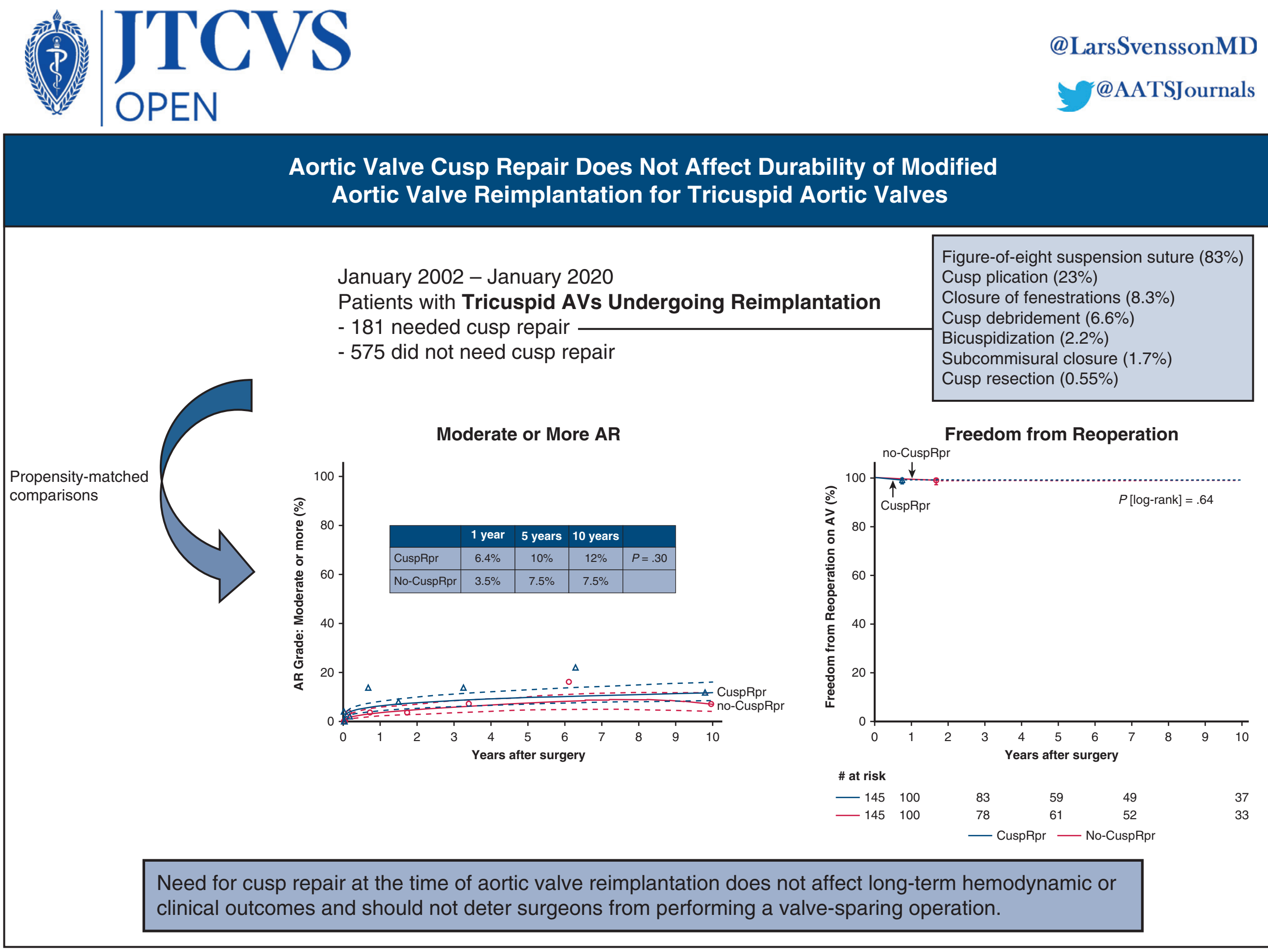


FIGURE 6. Patients with tricuspid aortic valves undergoing valve reimplantation during valve-sparing aortic root repair may also undergo cusp repair. Cusp repair is durable and does not adversely affect long-term valve hemodynamics. *AV*, Aortic valve; *AR*, aortic regurgitation; *CuspRpr*, cusp repair; *no-CuspRpr*, no cusp repair.

patients with dilated aortic roots, including those with AR requiring limited cusp repair. The need for aortic valve cusp repair does not affect long-term hemodynamic or clinical outcomes and should not deter surgeons from performing a valve-sparing operation (Figure 6).

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/aortic-valve-cusp-repair-does-not-affect-durability-of-aortic-valve-reimplantation-for-tricuspid-aortic-valves.

Conflict of Interest Statement

E.E.R. is a consultant and speaker for Artivion, Edwards, Medtronic, and Terumo Aortic; an inventor for Artivion; and on the advisory board for Edwards and Medtronic. 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: aortic regurgitation, aortic root aneurysm, aortic valve repair, valve-sparing aortic root replacement

APPENDIX E1. VARIABLES CONSIDERED IN ANALYSES

Demographics

Age (y),* sex,* race (White, Black, other),* height (cm),* weight (kg), body mass index ($kg \cdot m^{-2}$),* BSA (m^2)

Ventricular Function

Previous myocardial infarction*

Valve Pathology

Aortic valve regurgitation,* connective tissue disorder,* mitral valve regurgitation,* tricuspid valve regurgitation*

Mitral Valve Etiology

Degenerative*

Left Ventricular Structure and Function

LV inner diastolic diameter (cm), LV inner diastolic volume (mL), LV inner diastolic volume index (BSA),*

LV inner systolic diameter (cm), LV inner systolic volume (mL), LV inner systolic volume index (BSA),*

Posterior wall thickness (cm), relative wall thickness, IV septal thickness (cm), LV mass (g), LV mass index (BSA)*

Left Atrium Structure

LA diameter (cm), LA volume, LA volume index (BSA)

Aorta Dimension

Aortic sinus diameter, ratio: aortic root diameter/height (cm/m), ratio: aortic root area/height (cm^2/m),* mid-ascending aortic diameter*

Cardiac Comorbidities

Atrial fibrillation,* congestive heart failure,* history of cardiac surgery*

Noncardiac Comorbidities

Bilirubin (mg/dL),* creatinine (mg/dL),* blood urea nitrogen (mg/dL),* hematocrit (%),* history of peripheral artery disease,* history of hypertension,* history of treated diabetes,* history of chronic obstructive pulmonary disease,* history of smoking,* history of dyslipidemia*

Concomitant Procedures

Mitral valve repair,* coronary artery bypass graft*

Experience

Date of operation*

BSA, Body surface area; *LA*, left atrium; *LV*, left ventricular. *Variables used in the saturated model to estimate propensity scores.

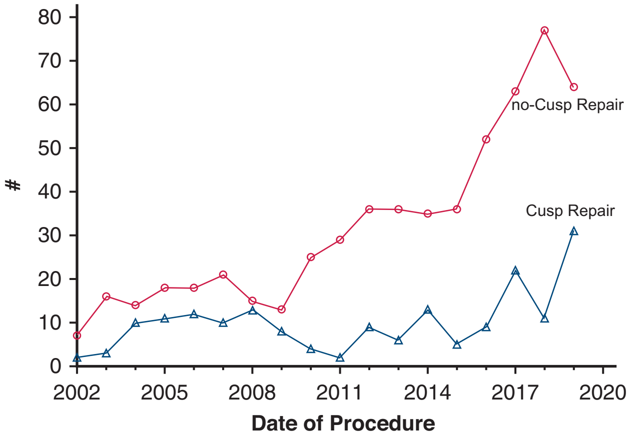

FIGURE E1. Temporal trend of number of patients undergoing tricuspid aortic valve–sparing root replacement with cusp repair (*blue line* and symbols) or without cusp repair (*red lines* and symbols) over the study period. Symbols are yearly number of cases in each group.

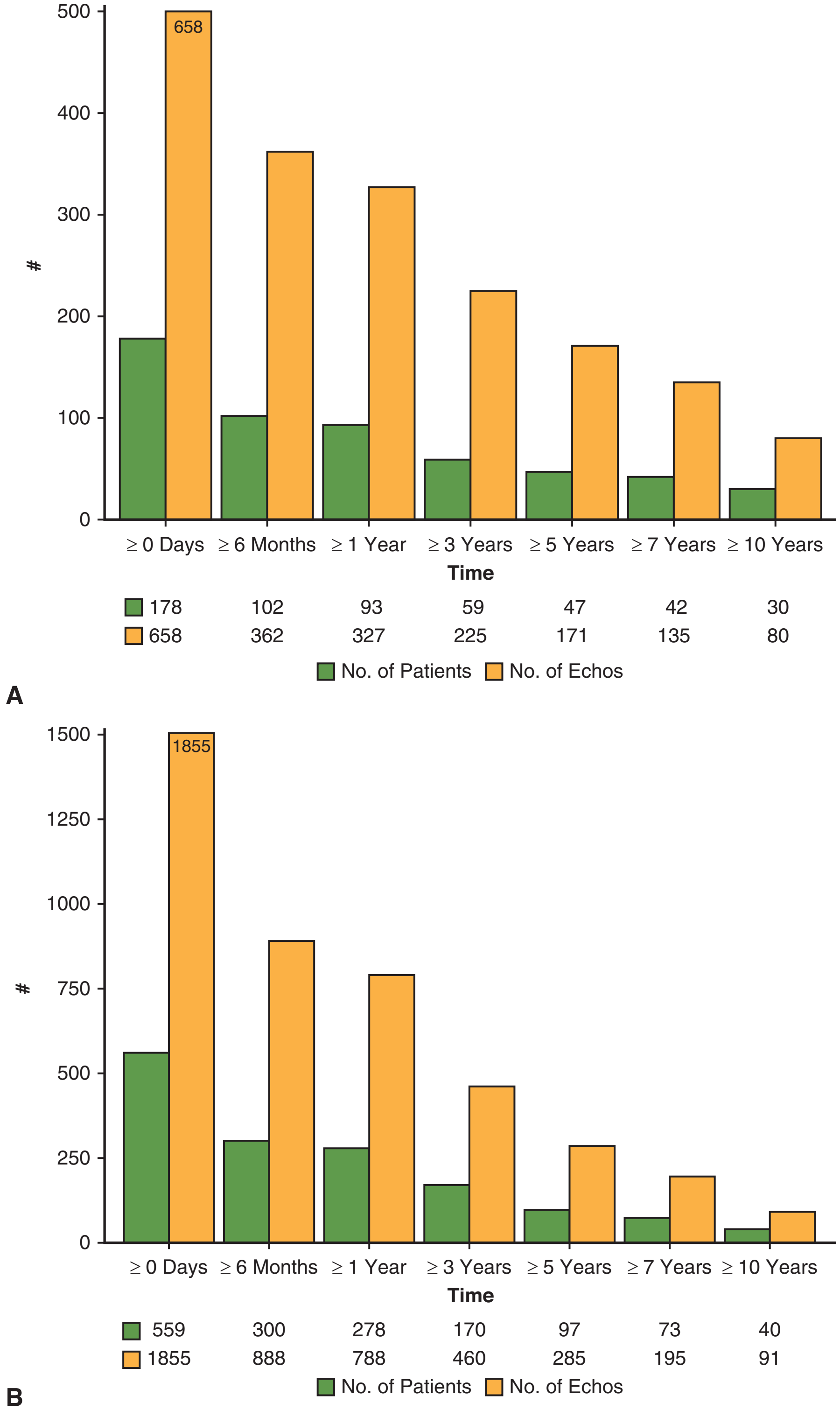

FIGURE E2. Echocardiographic follow-up across study period showing number of patients with echocardiograms over time and number of follow-up echocardiograms available at and beyond designated time points. A, Tricuspid aortic valve–sparing root reimplantation with aortic valve cusp repair. A total of 658 echocardiograms were evaluated for 178 patients. B, Tricuspid aortic valve–sparing root reimplantation without aortic valve cusp repair. A total of 1855 echocardiograms were evaluated for 559 patients.

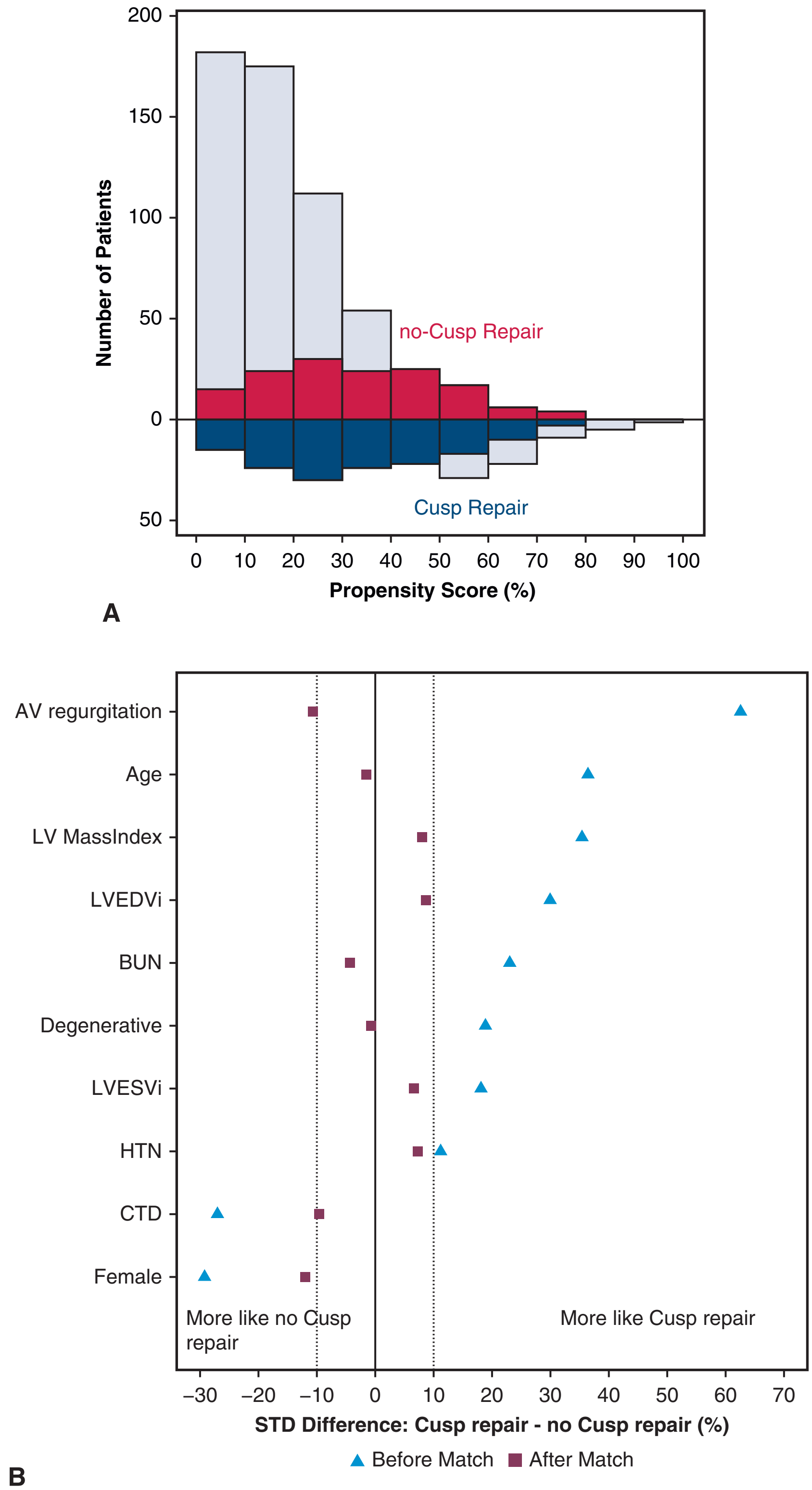

FIGURE E3. Quality of propensity score matching of patients undergoing tricuspid aortic valve–sparing root replacement with aortic valve cusp repair (*blue bars*) or without cusp repair (*red bars*). A, Mirrored histogram of distribution of propensity scores for both groups. Shaded areas represent matched patient pairs. B, Standardized differences of selected variables before and after matching. Vertical dashed lines at −10% and +10% indicate boundaries of desirable matching. *AV*, Aortic valve; *LV*, left ventricle; *LVEDVi*, left ventricular end-diastolic volume index; *BUN*, blood urea nitrogen; *LVESVi*, left ventricular end-systolic volume index; *HTN*, hypertension; *CTD*, connective tissue disease.

TABLE E1. Factors associated with tricuspid aortic valve–sparing root replacement with cusp repair (C-statistic = 0.69)

Factor	Coefficient ± SE	*P*	Reliability (%*)
Male	1.1 ± 0.28	<.0001	51
Higher grade of aortic valve regurgitation	0.62 ± 0.085	<.0001	90

SE, Standard error. *Reliability–bagging reliability; interpreted as proportion of 1000 bootstrap analyses in which this variable was retained with $P < .05$.