Long-term outcomes of rigid ring versus De Vega annuloplasty for functional tricuspid regurgitation: A propensity score-matching analysis

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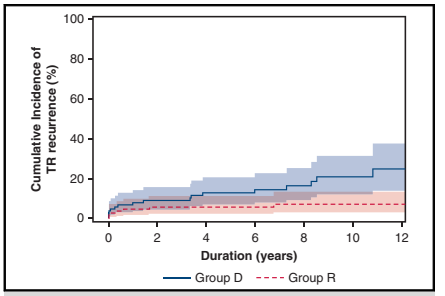
ABSTRACT

Objective: This study was conducted to compare the outcomes of rigid ring versus De Vega annuloplasty for the treatment of functional tricuspid regurgitation (TR).

Methods: From 2003 to 2017, De Vega annuloplasty (group D) was used in 231 patients, and rigid ring annuloplasty (group R) was used in 204 patients for the treatment of functional TR during left-sided valve surgery. A propensity score-matching analysis was used to pair group D (n = 109) with group R (n = 109). The primary outcomes were long-term overall survival and cardiac death, and the secondary outcomes were tricuspid valve-related events and TR recurrence (TR moderate or severe). The follow-up data were complete in 99.6% (447 out of 449) of the patients with a follow-up duration of 102 months.

Results: There were no differences in the overall survival and cardiac death between the propensity score-matched groups ($P = .793$ and $P = .175$, respectively) up to 14 years after surgery. Tricuspid valve-related events, including cardiac death, permanent pacemaker implantation, thromboembolism, bleeding and tricuspid valve reoperation were also similar between the 2 matched groups during the follow-up ($P > .999$). However, cumulative incidence of TR recurrence was significantly higher in group R than in group D ($P = .007$). Multivariate analysis indicated the annuloplasty method (De Vega) and preoperative TR grade as risk factors for late TR recurrence.

Conclusions: In functional TR, annuloplasty methods did not influence long-term overall survival, cardiac mortality, and tricuspid valve-related events. However, rigid ring annuloplasty showed less late TR recurrence. Rigid ring annuloplasty can be considered for the treatment of functional TR in terms of its better durability. (J Thorac Cardiovasc Surg 2021;161:1788-98)



Comparison of cumulative incidence of TR recurrence in De Vega versus rigid ring annuloplasty.

CENTRAL MESSAGE

Rigid ring annuloplasty is associated with less tricuspid regurgitation recurrence than De Vega annuloplasty in functional tricuspid regurgitation.

PERSPECTIVE

In functional tricuspid regurgitation, both De Vega and rigid ring annuloplasty demonstrated comparable results in long-term overall survival, cardiac mortality and tricuspid valve-related events; however, rigid ring annuloplasty showed less tricuspid regurgitation recurrence than did De Vega annuloplasty.

See Commentaries pages 1799, 1800, and 1801.

For the treatment of tricuspid regurgitation (TR), tricuspid annuloplasty (TAP) forms the mainstream of surgical management because TR is mostly functional secondary to left-sided valve disease in which annular dilatation without

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Abbreviations and Acronyms

IPW = inverse probability weighting
PASP = pulmonary artery systolic pressure
PSM = propensity score matching
TAP = tricuspid annuloplasty
TR = tricuspid regurgitation
TV = tricuspid valve
TVREs = tricuspid valve-related events

valvulopathy is typical manifestation of the disease.[1] There have been many TAP methods: suture TAP, including De Vega annuloplasty, Kay annuloplasty, and bicuspidalization; and ring TAP using a flexible band, semirigid ring, and rigid ring. Currently, De Vega or ring annuloplasty are the most commonly used methods among them.

Many studies have been conducted to compare suture annuloplasty versus ring annuloplasty or flexible ring versus rigid/semirigid ring annuloplasty, and their long-term results remain controversial. Moreover, most of the studies were designed to compare heterogenous groups in nature; for example, recruiting different types of rings to the same ring group.

Both De Vega and ring annuloplasty were simultaneously performed for decades in our institution, and we formerly reported excellent long-term outcomes of both techniques.[2,3] For this study, we selected the study patients to construct homogeneous groups, among which was the so-called measured De Vega TAP group and the other ring TAP group with only 1 type of rigid ring. The present study aimed to compare the long-term outcomes of rigid ring versus De Vega annuloplasty for treating functional TR during left-sided valve disease.

METHODS

The study protocol was reviewed by our institutional review board and approved as a minimal risk retrospective study (approval No.: H-1810-055-977) that did not require individual consent based on the institutional guidelines for waiving consent.

Study Population

From March 2003 to March 2017, 577 patients underwent TAP in our institution. Among them, patients who had no left-sided valve operation (75 patients), who underwent concomitant tricuspid valvuloplasty (14 patients), who had pulmonary valve disease (6 patients), who had active endocarditis (10 patients) and who underwent ring annuloplasty under De Vega base (7 patients) were excluded. The patients who received other than De Vega or rigid ring annuloplasty (30 patients) were excluded. De Vega TAP (group D) was performed in 231 patients and rigid ring annuloplasty (group R) was performed in 204 patients. Overall, 435 patients were enrolled in this study.

Surgical Procedure

All operations were performed under conventional cardiopulmonary bypass, mild or moderate hypothermia, and cardioplegic arrest through median sternotomy. Mitral or aortic valve operations were conducted before examining the tricuspid valve. In the case of the De Vega technique, 3-0 pledget-supported polytetrafluoroethylene mattress sutures were placed from the anteroseptal to posteroseptal commissure along the tricuspid annulus as widely performed by many surgeons. In our institution, we modified it to the so-called measured De Vega TAP in 2 aspects. First, we changed the suture material from polypropylene to polytetrafluoroethylene to reduce fracture and the guitar-string phenomenon. Second, we measured the reduced tricuspid annular diameter to improve the reproducibility.[4] Annular reduction was performed by tying the plication suture while the commercially available cylindrical valve sizer (Carpentier-Edwards Perimount valve sizer [Edwards Lifesciences, Irvine, Calif] for mitral valve) was inserted in the tricuspid valve (TV) orifice. Three sizers with actual diameters of 29.5 mm, 31.5 mm, and 33.5 mm (labeled sizes of 27 mm, 29 mm, and 31 mm) were used; however, the sizer with a diameter of 31.5 mm was used in a majority of patients.[2] Sizer was selected at the surgeon's discretion considering individual patient factors such as body surface area and the degree of annular dilatation. In the case of ring annuloplasty, an Edwards MC3 annuloplasty ring (Edwards Lifesciences) was implanted in all cases, and the size of the ring was determined by the surgeon based on the intercommissural distance of the septal leaflet. The indications of TAP for functional TR were TR of grade 1+ or more with annular dilatation or preoperative PASP >50 mm Hg. Annular dilatation was diagnosed if the annulus was larger than the tricuspid ring annuloplasty sizer that matched the intercommissural distance of the septal leaflet. Size properties of De Vega annuloplasty and ring annuloplasty are presented in Table E1; mean values of the sizers were 28.8 mm in the De Vega group and 30.0 mm in the ring group.

Echocardiographic Evaluation

All patients underwent preoperative transthoracic echocardiography and the severity of TR was evaluated. The severity of TR was graded as 0 for no regurgitation, 1 for mild regurgitation, 2 for moderate regurgitation, 3 for moderate to severe regurgitation, and 4 for severe regurgitation.[5] Postoperative echocardiography before discharge was performed at median 7 days (interquartile range, 6-11 days) in 98.9% of patients (430 out of 435) with the exception of a few operative mortality cases. During follow-up, echocardiographic evaluations were performed at the discretion of the operating surgeons. Follow-up echocardiography other than postoperative echocardiography was performed in 88.3% of patients (384 out of 435) patients, and the last follow-up echocardiography was performed in median 75 months (interquartile range, 35-112 months). TR recurrence was defined as moderate or greater (TR grade $\geq$2) documented at the final follow-up; although moderate or greater TR was detected during follow-up, it was not considered as TR recurrence if TR severity finally improved to less than moderate (TR <2) without additional procedures.

Evaluation of Clinical Outcomes

Operative mortality was defined as any death within 30 days after surgery or during the same hospital admission. Patients underwent regular postoperative follow-up at the outpatient clinic at 3- to 4-month intervals. Clinical follow-up ended on July 31, 2019. If patients did not visit the clinic at the scheduled time, they were contacted by telephone to confirm their condition. For patients who dropped out from the follow-ups, national health insurance data and information from the Statistics Korea, a central organization for statistics under the Korean Ministry of Strategy and Finance, were utilized to confirm survival or mortality date. The follow-up duration was median 102 months (interquartile range, 53-141 months). The following variables were evaluated as TV-related events (TVREs): cardiac death, permanent pacemaker insertion, thromboembolism, bleeding, and TV reoperation.[6] Cardiac death was defined as all deaths resulting from cardiac causes, including valve-related deaths, sudden unexplained deaths, and deaths from valve-nonrelated cardiac causes (eg, heart failure, acute myocardial infarction, or documented arrhythmias). Bleeding was

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TABLE 1. Preoperative characteristics and risk factors of patients

Variable	All study patients				Propensity score-matched patients			
	Group D (n = 231)	Group R (n = 204)	SMD	*P* value	Group D (n = 109)	Group R (n = 109)	SMD	*P* value
Age (y)	60.6 ± 11.1	58.2 ± 12.9	0.199	.038	60.1 ± 12.1	60.2 ± 10.4	–0.004	.978
Female	146 (63.2)	127 (62.3)	0.020	.838	72 (66.1)	75 (68.8)	–0.059	.674
BMI	22.1 ± 3.4	22.4 ± 3.1	–0.106	.273	22.1 ± 3.2	22.5 ± 3.1	–0.114	.404
BSA (m^2)	1.57 ± 0.19	1.58 ± 0.18	–0.049	.613	1.57 ± 0.17	1.57 ± 0.17	–0.038	.782
Risk factors								
Diabetes mellitus	31 (13.4)	26 (12.7)	0.020	.835	16 (14.7)	15 (13.8)	0.026	.827
Hypertension	54 (23.4)	38 (18.6)	0.117	.226	21 (19.3)	25 (22.9)	–0.090	.493
COPD	14 (6.1)	4 (2.0)	0.210	.051	5 (4.6)	4 (3.7)	0.046	.739
History of stroke	35 (15.2)	26 (12.7)	0.070	.471	19 (17.4)	15 (13.8)	0.101	.480
CKD	53 (22.9)	59 (28.9)	–0.137	.155	33 (30.3)	30 (27.5)	0.061	.639
CAD	13 (5.6)	8 (3.9)	0.080	.407	5 (4.6)	6 (5.5)	–0.042	.763
Atrial fibrillation	214 (92.6)	154 (75.5)	0.482	<.001	98 (89.9)	84 (86.2)	0.113	.317
Reoperation	74 (32.0)	12 (5.9)	0.708	<.001	12 (11.0)	11 (10.1)	0.030	.796
NYHA functional class ≥3	157 (68.0)	83 (40.7)	0.569	<.001	57 (52.3)	60 (55.0)	–0.055	.655
Dominant lesion								
Mitral valve	212 (91.8)	181 (88.7)	0.103	.283	102 (93.6)	99 (90.8)	0.103	.366
Aortic valve	19 (8.2)	23 (11.3)	–0.103	.283	7 (6.4)	10 (9.2)	–0.103	.366
Echocardiography								
LVEDD (mm)	55.0 ± 9.2	54.4 ± 8.7	0.073	.450	54.5 ± 8.5	54.4 ± 8.0	0.007	.961
LVESD (mm)	36.1 ± 7.9	36.3 ± 7.7	–0.027	.778	35.4 ± 7.4	35.9 ± 7.2	–0.071	.606
LVEF (%)	57.3 ± 8.5	55.4 ± 8.9	0.211	.029	56.9 ± 8.4	56.5 ± 8.2	0.051	.721
LA size (mm)	66.2 ± 15.1	60.3 ± 11.1	0.442	<.001	61.9 ± 12.4	63.3 ± 11.9	–0.118	.355
PASP (mm Hg)	50.5 ± 15.5	47.6 ± 14.3	0.194	.045	48.8 ± 16.4	49.1 ± 14.4	–0.015	.909
TR grade	2.03 ± 1.09	1.46 ± 1.03	0.541	<.001	1.81 ± 1.00	1.73 ± 1.19	0.069	.584
0 (none)	14 (6.1)	50 (24.5)			8 (7.3)	23 (21.1)		
1 (mild)	88 (38.1)	97 (47.5)			49 (45.0)	43 (39.4)		
2 (moderate)	72 (31.2)	30 (14.7)			33 (30.3)	20 (18.3)		
3 (moderate to severe)	15 (6.5)	7 (3.4)			6 (5.5)	5 (4.6)		
4 (severe)	42 (18.2)	20 (9.8)			13 (11.9)	18 (16.5)		

Values are presented as mean ± standard deviation for continuous data or as n (%). *SMD*, Standardized mean difference; *BMI*, body mass index; *BSA*, body surface area; *COPD*, chronic obstructive pulmonary disease; *CKD*, chronic kidney disease; *CAD*, coronary artery disease; *NYHA*, New York Heart Association; *LVEDD*, left ventricular end diastolic dimension; *LVESD*, left ventricular end systolic dimension; *LVEF*, left ventricular ejection fraction; *LA*, left atrium; *PASP*, pulmonary arterial systolic pressure; *TR*, tricuspid regurgitation.

defined as major internal or external bleeding that caused death, hospitalization, or permanent injury or necessitated transfusion.

Statistical Analysis

Statistical analysis was processed with SPSS (version 25.0; IBM-SPSS Inc, Armonk, NY) and SAS (version 9.4; SAS Institute Inc, Cary, NC) software. Continuous variables are presented as mean ± standard deviation, whereas categorical variables are presented as number and percentage of subjects. Propensity score analysis was utilized to overcome the selection bias attributed to the retrospective nature of this study. To produce propensity scores, we included 20 variables in the analysis: sex, age, body mass index, body surface area, diabetes mellitus, hypertension, chronic obstructive pulmonary disease, history of stroke, chronic kidney disease, New York Heart Association functional class ≥3, coronary artery disease, atrial fibrillation, reoperation, dominant valvular lesion (mitral vs aortic), left ventricle end-diastolic dimension, left ventricle end-systolic dimension, left ventricle ejection fraction, left atrial dimension, PASP, and TR grade (these last 6 are based on preoperative echocardiographic measurements). With the use of the caliper-matching method, pairs of patients were matched using a nearest neighborhood (greedy matching) within a caliper width of 0.1 in propensity scores, with a ratio of 1:1. (Figure E1) For inverse probability of treatment weight (IPW) analysis, IPWs were estimated by stabilizing and truncating the propensity scores: multiplying propensity scores by the unconditional probability of treatment group and then truncating them at first and 99th by replacing extreme weights at the truncated value. The balance of covariates between groups was evaluated with standardized mean differences. A standard mean difference ≤0.1 indicates negligible difference between groups. Comparison between the 2 groups was performed using the χ^2 test or Fisher exact test for categorical variables and the Student *t* test for continuous variables. For the comparison of categorical and continuous variables between the matched groups, the McNemar test and paired Student *t* test were used. Weighted *t* tests and weighted χ^2 test with IPW were used to compare continuous and categorical covariates between the groups. Overall survival was estimated using the Kaplan-Meier method, and unweighted or weighted Cox proportional hazards model was used for the comparisons of overall survival between the groups

in all patients and in propensity score matching (PSM) or IPW analysis using robust sandwich covariance matrix estimates in marginal Cox model approach to account for the intracluster correlation. For the analysis of cardiac death, TVREs and TR recurrence, cumulative incidence curves were estimated considering competing events. Noncardiac death was considered as a competing event for cardiac death and TVREs, and death was considered as a competing event for TR recurrence. Unweighted or weighted Fine and Gray regression model[7] was used for comparisons of cumulative incidence between the groups and for the analysis of risk factors for TR recurrence. Variables with a P value $< .2$ in the univariable analysis were included in the multivariable analysis. Subgroup analysis according to preoperative TR grade was conducted. Longitudinal analysis of postoperative TR grades was estimated using an ordinal logistic regression for repeated measurements by generalized estimating equation (SAS PROC GENMOD).

RESULTS

Preoperative Characteristics

In the overall cohort, group D had more patients with old age, atrial fibrillation, and reoperation than did group R. The preoperative New York Heart Association functional class was worse in group D than in group R. In terms of echocardiographic measurements, group D had more patients with a higher left ventricular ejection fraction, larger left atrial dimension, higher PASP and higher TR grade than group R. After PSM and IPW, the differences in baseline characteristics became statistically insignificant. (Table 1 and Table E2).

Operative Data and Early Clinical Outcomes

The cardiopulmonary bypass time (213 ± 58 vs 240 ± 49 minutes; $P < .001$) and aortic crossclamp time (150 ± 42 vs 163 ± 40 minutes; $P = .015$) was significantly shorter in group D than in group R after propensity score matching (Table 2). This result was consistent in IPW analysis (Table E3). The differences in procedural time might be associated with the finding that group R underwent concomitant arrhythmia surgery more frequently than did group D (85.3% vs 70.6%; $P = .008$). Mitral valve replacement was the predominantly performed procedure for left-sided valve disease in both groups (78.8% in group D vs 77.0% in group R). In terms of the etiology of left-sided valve lesion, rheumatic valvulopathy was the most common pathology in both groups (Table E4).

The operative mortality was not significantly different between the groups in the overall cohort (3.5% vs 3.4%; $P = .986$) and the matched cohort (2.8% vs 4.6%; $P = .480$). Regarding postoperative morbidities, low cardiac output syndrome (13.9% vs 4.4%; $P = .001$) and respiratory complication (10.8% vs 2.5%; $P = .001$) occurred

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TABLE 2. Comparison of operative data and early clinical outcomes

	All study patients			Propensity score-matched patients		
Variable	Group D (n = 231)	Group R (n = 204)	*P* value	Group D (n = 109)	Group R (n = 109)	*P* value
Procedural time						
CPB time (min)	223 ± 60	235 ± 50	.027	213 ± 58	240 ± 49	<.001
ACC time (min)	154 ± 44	159 ± 39	.222	150 ± 42	163 ± 40	.015
Left-sided valve operation						
MV repair	45 (19.5)	47 (23.0)	.364	26 (23.9)	23 (21.1)	.631
MV replacement	182 (78.8)	157 (77.0)	.647	82 (75.2)	86 (78.9)	.527
AV repair	8 (3.5)	4 (2.0)	.392	4 (3.7)	1 (0.9)	.180
AV replacement	63 (27.3)	61 (29.9)	.544	27 (24.8)	32 (29.4)	.446
Concomitant procedure						
Arrhythmia surgery	130 (56.3)	152 (74.5)	<.001	77 (70.6)	93 (85.3)	.008
Aorta surgery	11 (4.8)	16 (7.8)	.184	6 (5.5)	8 (7.3)	.564
CABG	3 (1.3)	7 (3.4)	.139	0 (0.0)	5 (4.6)	.063
Operative mortality	8 (3.5)	7 (3.4)	.986	3 (2.8)	5 (4.6)	.480
Postoperative morbidities						
LCOS	32 (13.9)	9 (4.4)	.001	11 (10.1)	6 (5.5)	.132
Respiratory complication	25 (10.8)	5 (2.5)	.001	7 (6.5)	3 (2.8)	.206
Acute kidney injury	13 (5.6)	10 (4.9)	.736	6 (5.5)	6 (5.5)	>.999
Bleeding reoperation	14 (6.1)	8 (3.9)	.310	5 (4.6)	5 (4.6)	>.999
Stroke	10 (4.3)	4 (2.0)	.184	4 (3.7)	3 (2.8)	.705
Mediastinitis	2 (0.9)	1 (0.5)	>.999	1 (0.9)	0 (0.0)	>.999
Complete AV block	1 (0.4)	0 (0.0)	>.999	1 (0.9)	0 (0.0)	>.999
Infective endocarditis	1 (0.4)	0 (0.0)	>.999	0 (0.0)	0 (0.0)	>.999

Values are presented as mean ± standard deviation for continuous data or n (%). *CPB*, Cardiopulmonary bypass; *ACC*, aortic crossclamp; *MV*, mitral valve; *AV*, aortic valve; *CABG*, coronary artery bypass grafting; *LCOS*, low cardiac output syndrome; *AV*, atrioventricular.

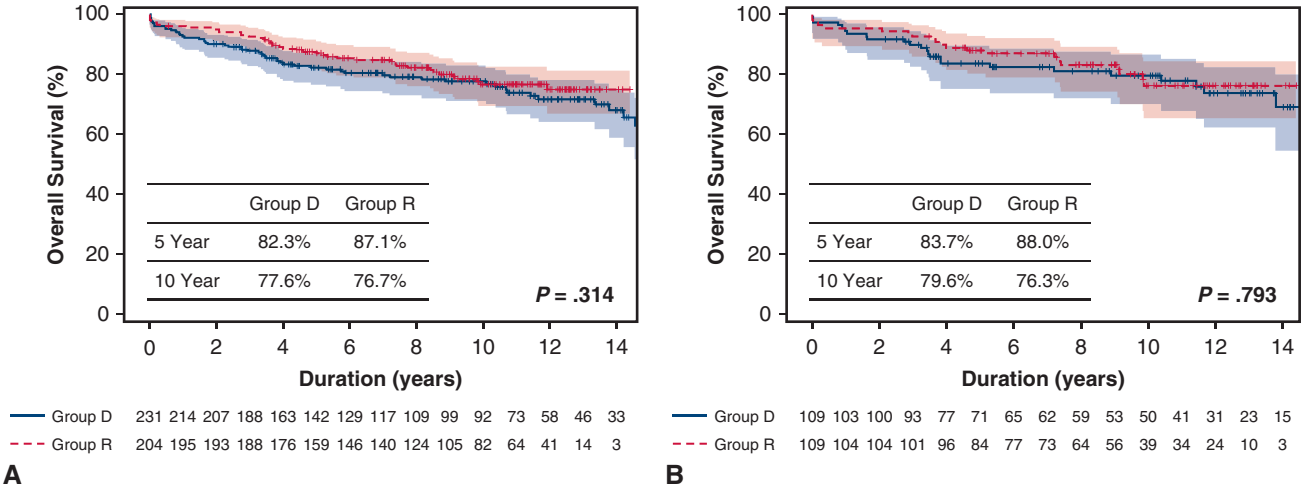


FIGURE 1. Comparison of overall survival between De Vega group and ring group. A, All patients. B, Propensity score-matched patients. There was no difference in overall survival between the groups in all patients and matched patients.

more frequently in group D in all study patients. After PSM, the incidences of postoperative morbidities were not different between the groups (Table 2).

Long-Term Clinical Outcomes

All-cause mortality occurred in 25.1% (58 out of 231) versus 20.6% (42 out of 204) of patients in group D versus group R, respectively. The overall survival at 5 years and 10 years in group D versus group R were 82.3% versus 87.1% and 77.6% versus 76.7%, respectively ($P = .314$). According to the PSM analysis ($P = .793$) and IPW analysis ($P = .939$), there was also no evidence of difference in overall survival (Figure 1).

Cardiac death occurred in 16.5% (38 out of 231) versus 6.9% (14 out of 204) of patients in group D versus group R, respectively. Cumulative incidences of cardiac death at 5 years and 10 years in group D versus group R were 12.3% versus 3.9% and 13.6% versus 7.5%, respectively ($P = .007$). PSM analysis showed no difference ($P = .175$) in cardiac mortality between the groups, whereas IPW analysis still presented significant difference ($P = .037$) (Figure 2).

TVREs occurred in 34.2% (79 out of 231) versus 24.0% (49 out of 204) of patients in group D versus group R, respectively. Cumulative incidences of TVREs at 5 years and 10 years in group D versus group R were 22.6% versus 13.4% and 31.3% versus 24.7%, respectively ($P = .018$). The difference became statistically insignificant after PSM analysis ($P > .999$) and IPW analysis ($P = .136$) (Figure E2).

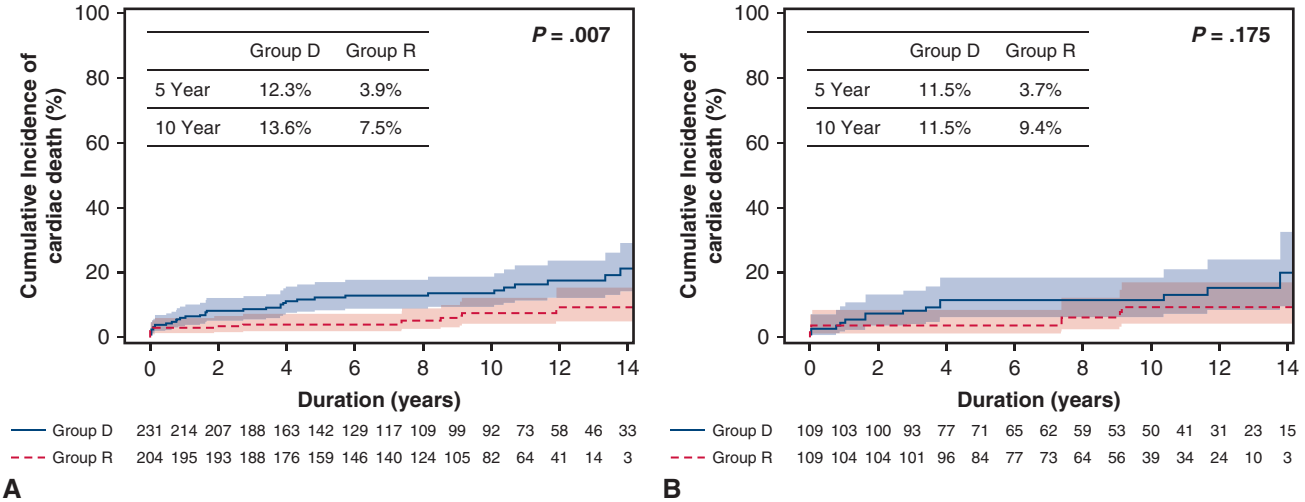


FIGURE 2. Comparison of cumulative incidence of cardiac death between De Vega group and ring group. A, All patients. B, Propensity score-matched patients. Cumulative incidence of cardiac death was significantly higher in De Vega group, but after propensity score matching, no difference was found between the groups.

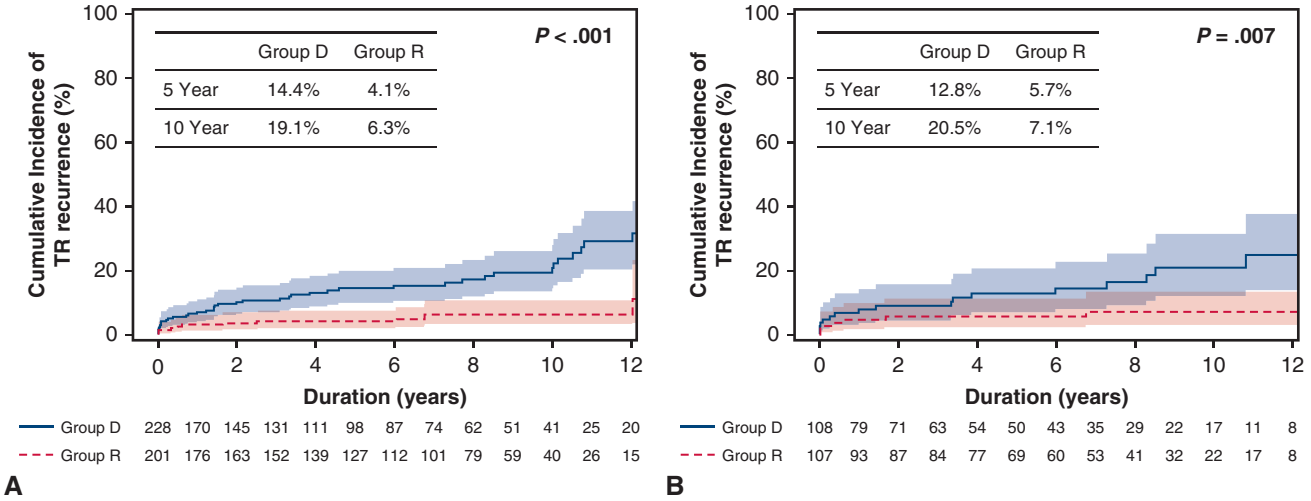


FIGURE 3. Comparison of cumulative incidence of tricuspid regurgitation (*TR*) recurrence between De Vega group and ring group. A, All patients. B, Propensity score-matched patients. Cumulative incidences of TR recurrence was significantly higher in the De Vega group, and this finding was consistent after propensity score matching.

TR recurrence occurred in 11.9% (27 out of 231) versus 1.5% (3 out of 204) of patients in group D versus group R, respectively. Cumulative incidences of TR recurrence at 5 years and 10 years in group D versus group R were 14.4% versus 4.1% and 19.1% versus 6.3%, respectively ($P < .001$). PSM analysis ($P = .007$) and IPW analysis ($P = .010$) consistently demonstrated that TR recurrence was significantly lower in group R (Figure 3).

Longitudinal analysis for TR grade was performed in all study population, PSM patients, and IPW cohorts. Group D consistently showed higher TR grade than group R in all periods and temporal trend toward TR recurrence compared with group R during follow-up (Figure 4 and Figure E3).

Risk Factor Analysis for TR Recurrence

Risk factor analysis was performed in overall patients. The multivariable analysis indicated annuloplasty method (De Vega) (hazard ratio [HR], 2.03; 95% confidence interval [CI], 0.93-4.45; $P = .076$) and preoperative TR grade (HR, 1.64; 95% CI, 1.28-2.09; $P < .001$) as risk factors for late TR recurrence (Table 3).

The effect of mitral valve repair versus replacement on late TR recurrence was evaluated by subgrouping 393 patients whose dominant left-sided valvular lesion was the mitral valve. The multivariable analysis showed that replacement was a risk factor for late TR recurrence (HR, 2.69; 95% CI, 1.16-6.23; $P = .021$) (Table E5).

Subgroup Analysis According to Preoperative TR Grade

A subgroup analysis was performed by extracting patients with preoperative TR grade of moderate or greater from both groups. There were 129 out of 231 (55.8%) patients in group D and 57 out of 204 (27.9%) patients in group R. No differences were identified in overall survival ($P = .253$), cumulative incidence of cardiac death ($P = .768$), cumulative incidence of TVREs ($P = .692$), and cumulative incidence of TR recurrence ($P = .193$).

In the subgroup analysis of preoperative TR grade of mild or less, 102 out of 231 (44.2%) patients in group D and 147 out of 204 (72.1%) patients in group R were enrolled. The overall survival ($P = .121$) was similar between the groups; however, cumulative incidence of cardiac death ($P = .004$), cumulative incidence of TVREs ($P = .025$), and cumulative incidence of TR recurrence ($P = .004$) were significantly lower in group R.

DISCUSSION

This study demonstrated 3 main findings. First, there was no evidence of difference between De Vega and rigid ring TAP for functional TR in terms of long-term all-cause mortality, cardiac mortality, and TVREs. Second, rigid ring TAP was superior to De Vega TAP for preventing late TR recurrence during follow-up. Third, the effect of rigid ring TAP over De Vega TAP was more prominent in preoperative less than moderate TR group than in preoperative moderate or greater TR group.

There have been many studies investigating suture versus ring tricuspid annuloplasty, and the superiority of ring over De Vega has been well-supported by several large studies[8-12]; however, some literature has reported comparable outcomes of De Vega over ring.[13,14] Among these studies regarding TAP methods, comparison between a homogenous De Vega group and homogenous rigid ring group has been rare. Hata and colleagues[13] observed no difference in the long-term outcomes between ring and suture

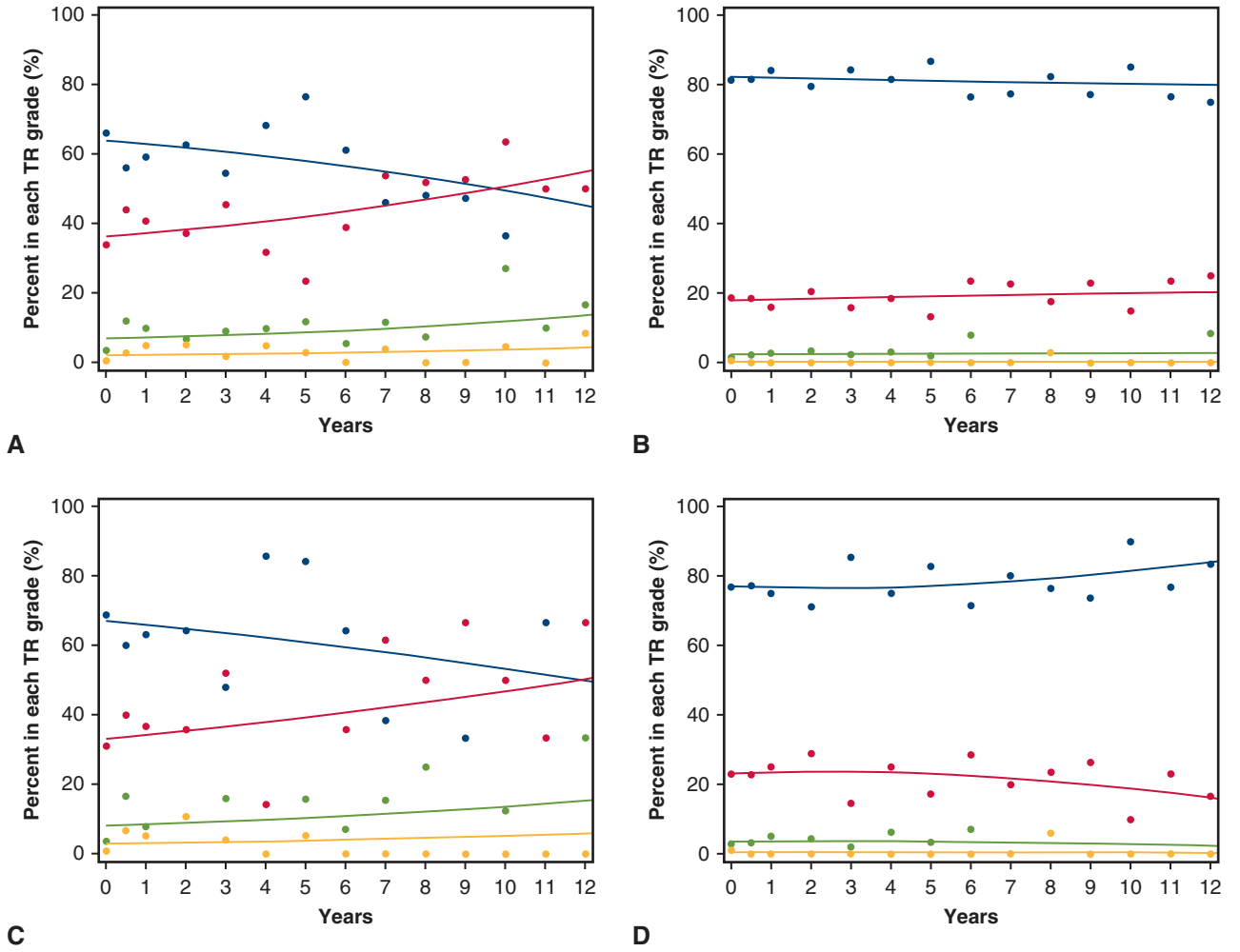


FIGURE 4. Longitudinal analysis for postoperative tricuspid regurgitation (*TR*) grade after tricuspid annuloplasty. A, De Vega group (all patients). B, Ring group (all patients). C, De Vega group (propensity score-matched patients). D, Ring group (propensity score-matched patients). The De Vega group consistently showed higher TR grade than the ring group in all periods and temporal trend toward TR recurrence compared with the ring group during follow-up. The following TR grades are presented: 0 (*blue*), 1 (*red*), 2 (*green*), or ≥3 (*yellow*).

TAP, although the postoperative mean TR grade was lower in the ring annuloplasty group. However, the authors composed the ring group (n = 372) with MC3 ring (n = 233), other rigid rings (n = 49), and several other flexible bands (n = 90). Gatti and colleagues[15] identified De Vega annuloplasty, compared with ring annuloplasty, as a risk factor (HR, 2.22; $P = .019$) for TR of moderate or greater during follow-up; however, the ring group included three rigid rings (n = 112) and 3 flexible bands (n = 337). A meta-analysis[12] also showed that ring annuloplasty was a protective factor for early mortality and long-term recurrence of TR; however, several suture techniques such as De Vega annuloplasty, Kay annuloplasty, and bicuspidalization composed the suture group, and several types of rings constituted the ring group. Guenther and colleagues[16] published a retrospective study that compared ring with suture annuloplasty and demonstrated that ring annuloplasty is associated with improved long-term survival and a lower reoperation rate. That study lacked information regarding late TR recurrence and recruited 2 types of rigid rings: 386 Carpentier-Edwards rings and 87 Edwards MC3 annuloplasty rings.

As previously described, so-called measured De Vega annuloplasty was implemented in our series, in which we had attempted to standardize TAP and produce better results. Moreover, we reported excellent outcomes of measured De Vega annuloplasty compared with classic De Vega annuloplasty elsewhere.[2] In contrast to other articles that did not describe standardization of the De Vega technique, our work might provide several strong points in terms of

TABLE 3. Multivariable subdistribution hazard model regression for tricuspid regurgitation (TR) recurrence

Variable	Univariate analysis		Multivariable analysis	
	P value	Hazard ratio (95% Confidence interval)	*P* value	Hazard ratio (95% Confidence interval)
Female versus male	.010	2.36 (1.23-4.54)	.283	1.73 (0.64-4.74)
Age (y)	.003	1.03 (1.01-1.05)	.438	1.01 (0.98-1.04)
BMI	.053	0.92 (0.85-1.00)	.799	1.02 (0.87-1.20)
BSA (m^2)	.004	0.06 (0.01-0.41)	.655	0.36 (0.00-31.75)
Diabetes mellitus	.058	1.92 (0.98-3.77)	.325	1.42 (0.71-2.85)
Hypertension	.512	0.78 (0.38-1.62)	–	–
COPD	.093	2.28 (0.87-5.96)	.619	1.28 (0.49-3.37)
History of stroke	.393	1.37 (0.67-2.81)	–	–
CKD	.338	1.32 (0.75-2.32)	–	–
CAD	.423	0.44 (0.06-3.25)	–	–
Atrial fibrillation	.028	4.76 (1.18-19.15)	.132	3.3 (0.70-15.66)
Reoperation	.374	1.32 (0.72-2.43)	–	–
NYHA class	.267	1.37 (0.79-2.37)	–	–
Dominant lesion*	.238	0.64 (0.3-1.34)	–	–
Maze	.199	0.70 (0.41-1.21)	.332	0.72 (0.38-1.39)
Aorta surgery	.880	0.91 (0.28-3.01)	–	–
CABG	.863	0.84 (0.11-6.33)	–	–
LVEDD (mm)†	.003	0.95 (0.92-0.98)	.567	0.98 (0.93-1.04)
LVESD (mm)†	.003	0.95 (0.92-0.98)	.605	0.99 (0.93-1.04)
LVEF (%)†	.914	1.00 (0.98-1.03)	–	–
LA size (mm)†	.729	1.00 (0.98-1.03)	–	–
PASP (mm Hg)†	.664	1.00 (0.99-1.02)	–	–
TR grade†	<.001	1.93 (1.59-2.35)	<.001	1.64 (1.28-2.09)
TAP method	<.001	3.44 (1.81-6.56)	.076	2.03 (0.93-4.45)

Missing values refer to hazard ratios of yes (vs no) for categorical variables or hazard ratios of a 1-unit change in tricuspid regurgitation grade and continuous variables. *BMI*, Body mass index; *BSA*, body surface area; *COPD*, chronic obstructive pulmonary disease; *CKD*, chronic kidney disease; *CAD*, coronary artery disease; *NYHA*, New York Heart Association; *CABG*, coronary artery bypass grafting; *LVEDD*, left ventricular end diastolic dimension; *LVESD*, left ventricular end systolic dimension; *LVEF*, left ventricular ejection fraction; *LA*, left atrium; *PASP*, pulmonary arterial systolic pressure; *TAP*, tricuspid annuloplasty. *Dominant left-sided valve lesion: mitral versus aortic. †Preoperative measurements.

standardization that will consequently further support the superiority of rigid ring TAP over De Vega TAP.

Our group previously reported that routine TAP (ring or De Vega) at the time of mitral valve replacement can be beneficial even if TR grade is less than mild to moderate.[17] According to the subgroup analysis presented in this study, the protective effect of ring TAP on late TR recurrence was more prominent in TR grade less than moderate than TR grade moderate or greater. This finding further supports our previous findings of the usefulness of TAP in nonsignificant TR.

According to our analyses, the TAP method was associated with TR recurrence during long-term follow-up. The mean follow-up duration was 94 months, which is sufficiently long; however, given that late TR recurrence typically matters 10 years after operation,[18] further follow-up is required for investigating its clinical significance. Similarly, although the TAP method showed no differences in overall survival, cardiac mortality and TVREs, continuous follow-up beyond 10 years would be important to confirm the findings.

Although the TAP method has been demonstrated to have little influence on long-term overall survival, long-term cardiac death and valve-related events in many studies, its clinical importance must not be overlooked in terms of performance status and quality of life. Ren and colleagues[19] showed that ring TAP was associated with less TR recurrence and a higher quality of life than was De Vega TAP. Similarly, worse functional class and more admissions due to heart failure, although further analysis required, was observed more frequently in the De Vega group in our study population.

The reason for the superiority of rigid ring annuloplasty is assumed to be as follows: the tricuspid annulus

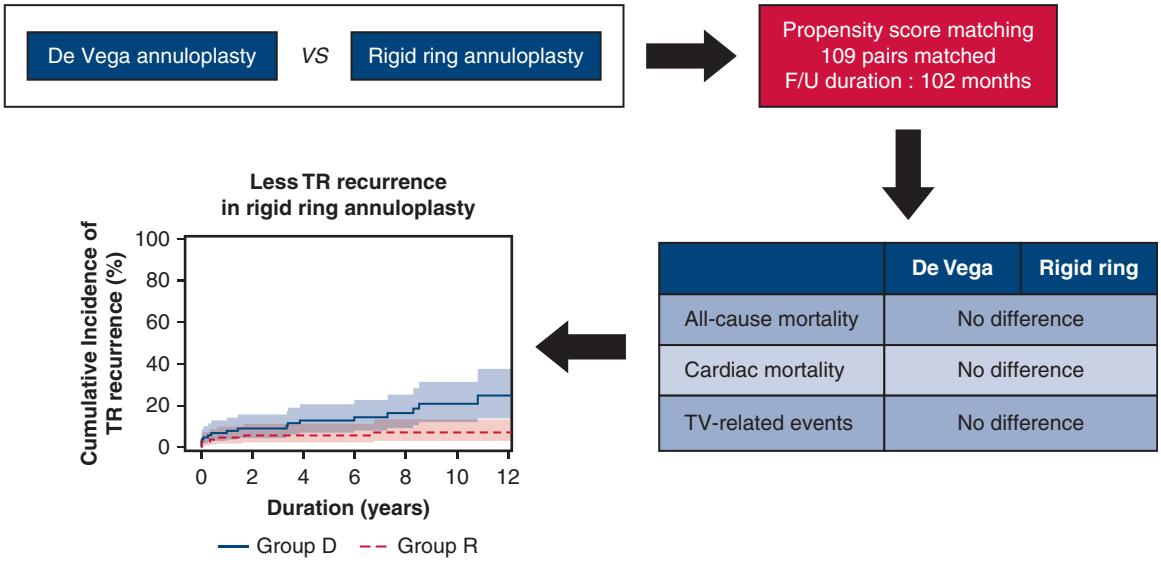


FIGURE 5. To compare long-term outcomes of rigid ring versus De Vega annuloplasty for functional tricuspid regurgitation (*TR*), this study was performed using propensity score matching analysis. In terms of functional TR, annuloplasty methods did not influence long-term overall survival, cardiac mortality, and tricuspid valve (*TV*)-related events; however, rigid ring annuloplasty showed less TR recurrence than De Vega annuloplasty. *F/U*, Follow-up.

has a nonplanar, saddle-shaped, 3-dimensional structure.[20] Experimental[21] and clinical[22] studies have confirmed the complex tricuspid geometry and motion during the cardiac cycle. When TR worsens, the 3-dimensional structure of the TV annulus changes and becomes a circular shape with a planar structure. In this situation, Carpentier and colleagues[23] developed the idea of remodeling the annulus using a ring. Ring annuloplasty remodels the annulus, decreases tension on suture lines, increases leaflet coaptation, and prevents recurrent annular dilatation. Among the several types of annuloplasty rings, the Edwards MC3 ring is among the rigid rings and its own characteristic of a 3-dimensional profile based on the geometry of the normal tricuspid annulus is believed to contribute to better long-term results than is De Vega annuloplasty for TV repair.[24]

When assessing the results derived from this study, the different methodology for sizing between the ring and De Vega annuloplasty should be taken into consideration in that it may account for the differential outcomes observed. In case of De Vega, the Carpentier-Edwards Perimount sizer is circular in shape and annuloplasty is planar in plane. In case of ring, the ring is not circular in shape and has 3-dimensional geometry. Thus, it is certain that simple comparison of the diameter of the sizers is not adequate. On the other hand, the 2 groups might be quite comparable in terms of sizer diameter, allowing for the fact that average 31.5 mm circular sizer was used for De Vega, whereas average 30.0 mm elliptical sizer was used for the rigid ring.

Limitations

This study has several limitations to be noted. First, this study was a retrospective observational study performed at a single institution. Second, as previously described, longer-term follow-up beyond 10 years might be required to clarify the manifestation of late TR recurrence after TAP. Third, the sample size was relatively small; thus, the baseline characteristics and risk factors between the groups were not perfectly controlled despite PSM and IPW, and the results might be biased. Fourth, in analyzing the risk factors for TR recurrence, some concerns might exist about the statistical method that multivariable regression using significant variables from univariate regression has poor statistical properties. Also, subgroup analyses according to preoperative TR grade and mitral valve repair versus replacement were unadjusted. Fifth, right-sided cardiac catheterization data would be helpful in measuring PASP and evaluating TR recurrence; however, it was not routinely performed during the study period. Finally, we did not include several factors such as preoperative left-sided pathology, its postoperative clinical status, right ventricular size and function, tricuspid annulus size, TV tethering, and the condition of right ventricular reverse remodeling that would be associated with the TR recurrence.

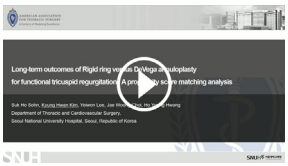
CONCLUSIONS

In functional TR, annuloplasty methods did not influence long-term overall survival, cardiac mortality, and TVREs during the observation period. However, rigid ring

annuloplasty showed less TR recurrence. Rigid ring annuloplasty can be considered for the treatment of functional TR in terms of its better durability (Figure 5).

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/19%20AM/Monday_May6/206F/206F/S81%20-%20Tricuspid%20valve%20surgery%20essentials/S81_7_webcast_030444140.mp4.



References

1. Rodés-Cabau J, Taramasso M, O'Gara PT. Diagnosis and treatment of tricuspid valve disease: current and future perspectives. *Lancet*. 2016;388:2431-42.
2. Hwang HY, Chang HW, Jeong DS, Ahn H. De Vega annuloplasty for functional tricupsid regurgitation: concept of tricuspid valve orifice index to optimize tricuspid valve annular reduction. *J Korean Med Sci*. 2013;28:1756-61.
3. Choi JW, Kim KH, Kim SH, Yeom SY, Hwang HY, Kim KB. Long-term results of tricuspid annuloplasty using MC3 ring for functional tricuspid regurgitation. *Circ J*. 2018;82:2358-63.
4. Antunes MJ. De Vega annuloplasty of the tricuspid valve. *Oper Tech Thorac Cardiovasc Surg*. 2003;8:169-76.
5. Zoghbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA, et al. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. *J Am Soc Echocardiogr*. 2003;16:777-802.
6. Akins CW, Miller DC, Turina MI, Kouchoukos NT, Blackstone EH, Grunkemeier GL, et al. Guidelines for reporting mortality and morbidity after cardiac valve interventions. *Ann Thorac Surg*. 2008;85:1490-5.
7. Austin PC, Fine JP. Practical recommendations for reporting Fine-Gray model analyses for competing risk data. *Stat Med*. 2017;36:4391-400.
8. Rivera R, Duran E, Ajuria M. Carpentier's flexible ring versus De Vega's annuloplasty. A prospective randomized study. *J Thorac Cardiovasc Surg*. 1985;89:196-203.
9. McCarthy PM, Bhudia SK, Rajeswaran J, Hoercher KJ, Lytle BW, Cosgrove DM, et al. Tricuspid valve repair: durability and risk factors for failure. *J Thorac Cardiovasc Surg*. 2004;127:674-85.
10. Tang GH, David TE, Singh SK, Maganti MD, Armstrong S, Borger MA. Tricuspid valve repair with an annuloplasty ring results in improved long-term outcomes. *Circulation*. 2006;114(1 Suppl):I577-81.
11. Navia JL, Nowicki ER, Blackstone EH, Brozzi NA, Nento DE, Atik FA, et al. Surgical management of secondary tricuspid valve regurgitation: annulus, commissure, or leaflet procedure? *J Thorac Cardiovasc Surg*. 2010;139:1473-82.
12. Parolari A, Barili F, Pilozzi A, Pacini D. Ring or suture annuloplasty for tricuspid regurgitation? A meta-analysis review. *Ann Thorac Surg*. 2014;98:2255-63.
13. Hata H, Fujita T, Miura S, Shimahara Y, Kume Y, Matsumoto Y, et al. Long-term outcomes of suture vs. ring tricuspid annuloplasty for functional tricuspid regurgitation. *Circ J*. 2017;81:1432-8.
14. Shinn SH, Dayan V, Schaff HV, Dearani JA, Joyce LD, Lahr B, et al. Outcomes of ring versus suture annuloplasty for tricuspid valve repair in patients undergoing mitral valve surgery. *J Thorac Cardiovasc Surg*. 2016;152:406-15.
15. Gatti G, Dell'Angela L, Morosin M, Maschietto L, Pinamonti B, Forti G, et al. Tricuspid annuloplasty for tricuspid regurgitation secondary to left-sided heart valve disease: immediate outcomes and risk factors for late failure. *Can J Cardiol*. 2016;32:760-6.
16. Guenther T, Mazzitelli D, Noebauer C, Hettich I, Tassani-Prell P, Voss B, et al. Tricuspid valve repair: is ring annuloplasty superior? *Eur J Cardiothorac Surg*. 2013;43:58-65.
17. Choi JW, Kim KH, Chang HW, Jang MJ, Kim SH, Yeom SY, et al. Long-term results of annuloplasty in trivial-to-mild functional tricuspid regurgitation during mitral valve replacement: should we perform annuloplasty on the tricuspid valve or leave it alone? *Eur J Cardiothorac Surg*. 2018;53:756-63.
18. Kwak JJ, Kim YJ, Kim MK, Kim HK, Park JS, Kim KH, et al. Development of tricuspid regurgitation late after left-sided valve surgery: a single-center experience with long-term echocardiographic examinations. *Am Heart J*. 2008;155:732-7.
19. Ren WJ, Zhang BG, Liu JS, Qian YJ, Guo YQ. Outcomes of tricuspid annuloplasty with and without prosthetic rings: a retrospective follow-up study. *J Cardiothorac Surg*. 2015;10:81.
20. Fukuda S, Saracino G, Matsumura Y, Daimon M, Tran H, Greenberg NL, et al. Three-dimensional geometry of the tricuspid annulus in healthy subjects and in patients with functional tricuspid regurgitation: a real-time, 3-dimensional echocardiographic study. *Circulation*. 2006;114:I492-8.
21. Tsakiris AG, Mair DD, Seki S, Titus JL, Wood EH. Motion of the tricuspid valve annulus in anesthetized intact dogs. *Circ Res*. 1975;36:43-8.
22. Tei C, Pilgrim JP, Shah PM, Ormiston JA, Wong M. The tricuspid valve annulus: study of size and motion in normal subjects and in patients with tricuspid regurgitation. *Circulation*. 1982;66:665-71.
23. Carpentier A, Deloche A, Dauptain J, Soyer R, Blondeau P, Piwnica A, et al. A new reconstructive operation for correction of mitral and tricuspid insufficiency. *J Thorac Cardiovasc Surg*. 1971;61:1-13.
24. Jeong DS, Kim KH. Tricuspid annuloplasty using the MC3 ring for functional tricuspid regurgitation. *Circ J*. 2010;74:278-83.

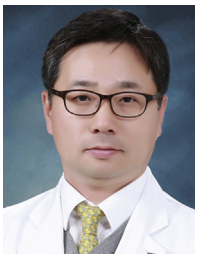
Key Words: tricuspid regurgitation, tricuspid annuloplasty

ADULT

Discussion

Dr Percy Boateng *(New York, NY)*. Thank you, Dr Kim, for your presentation. I have a few questions, but just to summarize what you said, in your experience in your institution there was no difference in the long-term outcome and freedom from cardiac death, tricuspid-related events, which are listed as thromboembolism, permanent pacemaker implantation, bleeding, reoperations or morbidity in patients who were propensity matched, and the follow-up time was 94 months median up to 51 months, somewhat of a range of about 10 years.

The first question I have is, if there is no difference in the ring that you choose or the prosthesis that you choose, should anyone be doing a rigid ring for selective patients or does it make a difference? The De Vega is clearly cheaper. Why would you want to use a more expensive ring if there is no difference in outcomes, because primarily the purpose of the annuloplasty is to prevent morbidity and mortality down the line, and if we are not making a difference in the patient's morbidity or mortality, then does it make a difference what ring we use, or should we be doing any rings at all?



Dr Kyung Hwan Kim *(Seoul, Republic of Korea)*. Thank you for your question. It is not the issue of the cost or expense. According to our 2008 article, in which we analyzed more than 600 patients who underwent left-sided valve surgery without significant tricuspid regurgitation (TR), significant TR with poor prognosis occurred in around 27% after more than 10 years, average 11.3 years later. So we have aggressively performed tricuspid annuloplasty, any kind of annuloplasty, for functional TR. That is our policy. Suture annuloplasty versus ring annuloplasty, the choice is up to surgeon's discretion. In terms of suture annuloplasty, our results were relatively excellent because we used the polytetrafluoroethylene suture, not polypropylene suture, to prevent guitar-string effect and we measured the tricuspid valve area after annuloplasty using the tissue valve sizer. These were our endeavors to standardize the tricuspid annuloplasty and to improve surgical outcomes. On the other hand, ring annuloplasty is supported by many surgeons because of its remodeling effect and reproducibility. My preference is ring annuloplasty, but there is intrainstitutional variability.

Dr Boateng. So then is it fair to say that TR, as we all know, eventually leads to significant morbidity and mortality, maybe beyond 10 years, that your study did not go far enough to detect a difference? Maybe a sample size with a smaller group would detect a difference?

Dr Kim. In fact, I have never seen a report that says, "Our sample size is sufficient," especially regarding TR. Despite the small sample size with fewer than 10 years of follow-up, we observed significant difference in TR recurrence. We expect this will matter at longer-term follow-up, although it did not show any difference in mortality and morbidity in this study. In addition to longer-term follow-up, we hope a multicenter trial to be conducted because it is very difficult to get sufficient evidence from a single institution.

Dr Boateng. The other thing that you included in your analysis is cardiac death. The primary procedure that was done was left-sided heart surgery. How do you explain using cardiac death as an end point when you were looking at TR? Could the primary procedure, which was either an aortic valve replacement or a mitral valve replacement, the failure of that procedure could have been the cause of cardiac death and not because of TR?

Dr Kim. It is true that, as you pointed out, the long-term clinical outcomes, including cardiac mortality, tricuspid valve-related events, and even TR recurrence would be greatly associated with the left-sided pathology and how well it was treated. In this study, we could not analyze the results considering the clinical status of left-sided lesion, because stratifying the patients according to their left-sided pathology and valvular function would be very complicated, and in fact, there were a small number of patients with recurrent mitral reguritation or prosthetic mitral valve failure. Your point would be a limitation of our study.

Dr Boateng. And in your experience with the patient population that you studied, those who have recurrent maybe early or midterm severe TR, did they have higher morbidity or mortality? I didn't see that clearly.

Dr Kim. We have not observed clear evidence of higher mortality or morbidity in recurrent TR patients in this study. But we got some impression that patients with recurrent TR presented worsening symptoms during follow-up periods, and we anticipate this will influence clinical outcomes with longer-term follow-up. Another article published by our institution also supports our impression.

Dr Boateng. I just want a clarification, you showed that patients who had mitral valve replacement tend to have a much higher recurrence of TR. Were you able to glean any information from your dataset why that is the case? Was it because of early valve failure, or stenosis? Were there any particular features of those patients that may have led to earlier recurrence of TR than the patients who had mitral valve repair?

Dr Kim. Actually I don't exactly know the reason why the mitral valve replacement group presented worse outcomes than the repair group in terms of TR recurrence. One thing is that replacement group mostly belonged to rheumatic disease while repair group to degenerative disease. This might have caused the difference between the 2 groups, although the exact mechanism is unknown. Anyway, in case of less than mild to moderate TR with left-sided valve surgery, my surgical principle is not doing any procedure on the tricuspid valve in degenerative mitral regurgitation, while doing tricuspid annuloplasty in rheumatic mitral disease.

Dr Boateng. Thank you very much. Good talk, great study.

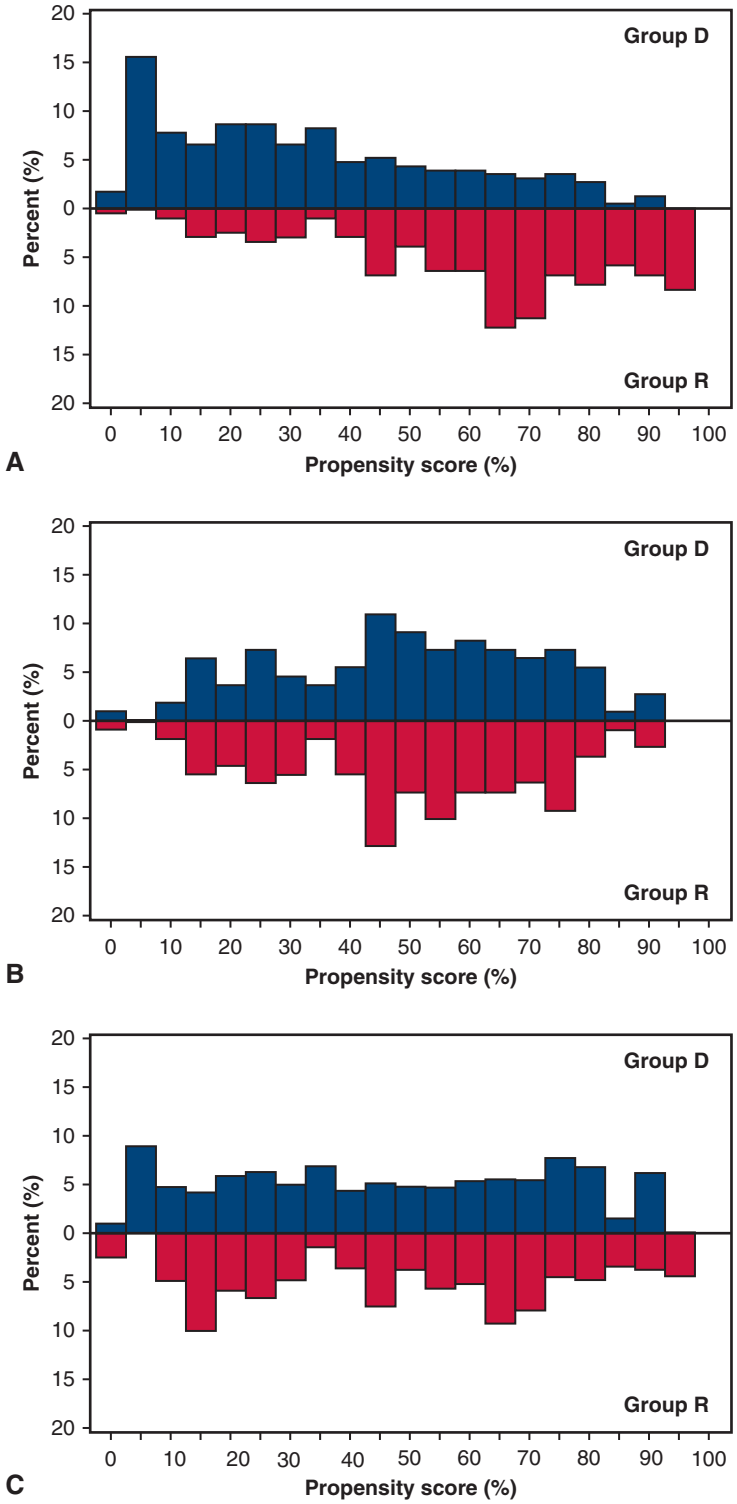


FIGURE E1. Mirror histogram of the propensity scores. A, All patients. B, Propensity score-matched patients. C, Inverse probability-weighted (IPW) patients.

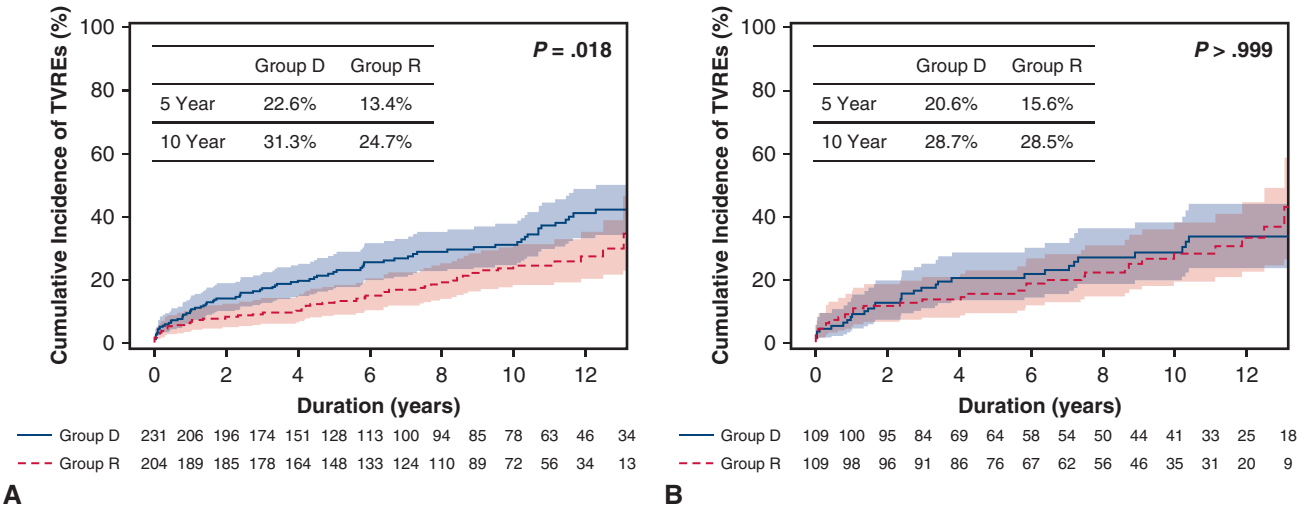


FIGURE E2. Comparison of cumulative incidence of tricuspid valve-related events (*TVREs*) between Group D and Group R. A, All patients. B, Propensity score-matched patients. Cumulative incidence of TVREs was significantly higher in the De Vega group, but after propensity score matching, no difference was found between the groups.

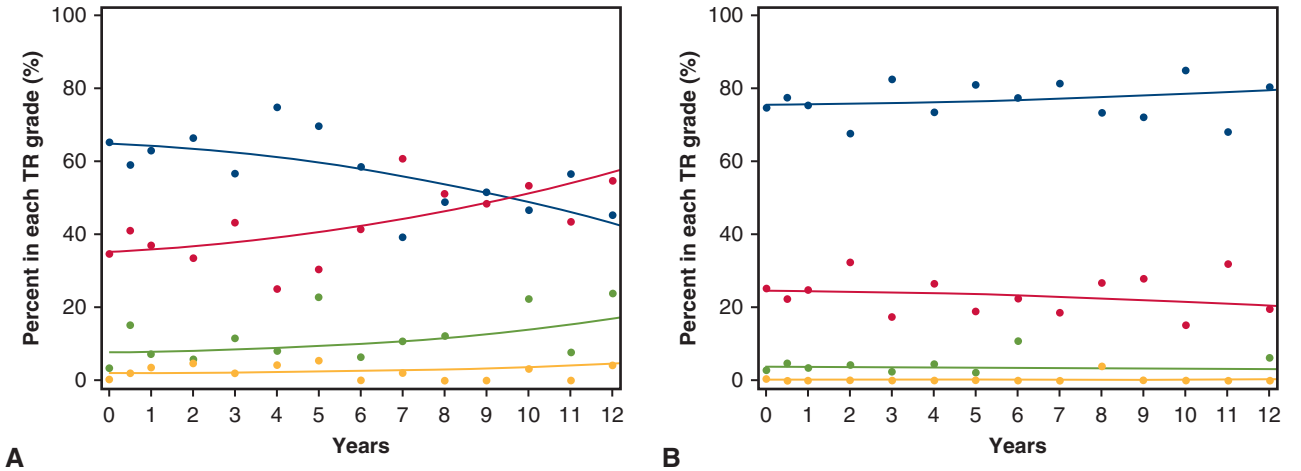


FIGURE E3. Longitudinal analysis for postoperative tricuspid regurgitation (*TR*) grade after tricuspid annuloplasty. A, De Vega group (inverse probability-weighted [IPW] patients), B, Ring group (IPW patients). The De Vega group consistently showed higher TR grade than the ring group in all periods and temporal trend toward TR recurrence compared with the ring group during follow-up. The following TR grades are presented: 0 (*blue*), 1 (*red*), 2 (*green*), or ≥3 (*yellow*).

TABLE E1. Size properties of De Vega annuloplasty and ring annuloplasty

Carpentier-Edwards Perimount sizer* (mm)	Group D (n = 231)	Edwards MC3 annuloplasty ring sizer* (mm)	Group R (n = 204)
27	42 (18.2)	28	74 (36.3)
29	168 (72.7)	30	77 (37.7)
31	19 (8.2)	32	36 (17.6)
33	2 (0.9)	34	12 (5.9)
		36	5 (2.5)

Values are presented as n (%). *Edwards Lifesciences, Irvine, Calif.

TABLE E2. Preoperative characteristics and risk factors of the patients with inverse probability weighting (IPW) analysis

Variable	All study patients				IPW analysis			
	Group D (n = 231)	Group R (n = 204)	SMD	*P* value	Group D (n = 231)	Group R (n = 204)	SMD	*P* value
Age (y)	60.6 ± 11.1	58.2 ± 12.9	0.199	.038	59.5 ± 11.1	59.3 ± 11.7	0.012	.905
Female	146 (63.2)	127 (62.3)	0.020	.838	146 (65.4)	127 (65.5)	–0.002	.981
BMI	22.1 ± 3.4	22.4 ± 3.1	–0.106	.273	22.1 ± 3.3	22.2 ± 3.0	–0.045	.643
BSA	1.57 ± 0.19	1.58 ± 0.18	–0.049	.613	1.57 ± 0.18	1.57 ± 0.17	–0.032	.747
Risk factors								
Diabetes mellitus	31 (13.4)	26 (12.7)	0.020	.835	31 (12.9)	26 (12.5)	0.011	.910
Hypertension	54 (23.4)	38 (18.6)	0.117	.226	54 (20.0)	38 (18.3)	0.043	.663
COPD	14 (6.1)	4 (2.0)	0.210	.051	14 (4.2)	4 (3.0)	0.067	.498
History of stroke	35 (15.2)	26 (12.7)	0.070	.471	35 (16.0)	26 (16.1)	–0.002	.981
CKD	53 (22.9)	59 (28.9)	–0.137	.155	53 (25.1)	59 (26.6)	–0.035	.718
CAD	13 (5.6)	8 (3.9)	0.080	.407	13 (4.8)	8 (3.8)	0.051	.603
Atrial fibrillation	214 (92.6)	154 (75.5)	0.482	<.001	214 (85.3)	154 (84.7)	0.016	.871
Reoperation	74 (32.0)	12 (5.9)	0.708	<.001	74 (19.9)	12 (15.1)	0.127	.197
NYHA class ≥3	157 (68.0)	83 (40.7)	0.569	<.001	157 (56.7)	83 (50.6)	0.122	.213
Dominant lesion								
Mitral valve	212 (91.8)	181 (88.7)	0.103	.283	212 (88.7)	181 (91.3)	–0.087	.377
Aortic valve	19 (8.2)	23 (11.3)	–0.103	.283	19 (11.3)	23 (8.7)	0.087	.377
Echocardiography								
LVEDD (mm)	55.0 ± 9.2	54.4 ± 8.7	0.073	.450	54.6 ± 8.6	54.5 ± 8.0	0.021	.827
LVESD (mm)	36.1 ± 7.9	36.3 ± 7.7	–0.027	.778	36.2 ± 7.3	36.0 ± 7.0	0.022	.819
LVEF (%)	57.3 ± 8.5	55.4 ± 8.9	0.211	.029	56.1 ± 9.3	56.2 ± 8.0	–0.013	.893
LA size (mm)	66.2 ± 15.1	60.3 ± 11.1	0.442	<.001	63.4 ± 14.0	63.1 ± 11.7	0.021	.827
PASP (mmHg)	50.5 ± 15.5	47.6 ± 14.3	0.194	.045	49.2 ± 15.5	48.9 ± 14.3	0.023	.818
TR grade	2.03 ± 1.09	1.46 ± 1.03	0.541	<.001	1.84 ± 1.00	1.86 ± 1.22	–0.021	.833
0 (none)	14 (6.1)	50 (24.5)			14 (6.8)	50 (17.3)		
1 (mild)	88 (38.1)	97 (47.5)			88 (45.1)	97 (41.3)		
2 (moderate)	72 (31.2)	30 (14.7)			72 (30.0)	30 (15.8)		
3 (moderate to severe)	15 (6.5)	7 (3.4)			15 (5.3)	7 (4.8)		
4 (severe)	42 (18.2)	20 (9.8)			42 (12.8)	20 (20.8)		

Values are presented as mean ± standard deviation for continuous data or n (%). *SMD*, Standardized mean difference; *BMI*, body mass index; *BSA*, body surface area; *COPD*, chronic obstructive pulmonary disease; *CKD*, chronic kidney disease; *CAD*, coronary artery disease; *NYHA*, New York Heart Association; *LVEDD*, left ventricular end diastolic dimension; *LVESD*, left ventricular end systolic dimension; *LVEF*, left ventricular ejection fraction; *LA*, left atrium; *PASP*, pulmonary arterial systolic pressure; *TR*, tricuspid regurgitation.

TABLE E3. Comparison of operative data and early clinical outcomes with inverse probability weighting (IPW) analysis

Variable	All study patients			IPW Analysis		
	Group D (n = 231)	Group R (n = 204)	*P* value	Group D (n = 231)	Group R (n = 204)	*P* value
Procedural time						
CPB time (min)	223 ± 60	235 ± 50	.027	215 ± 58	241 ± 48	<.001
ACC time (min)	154 ± 44	159 ± 39	.222	152 ± 42	165 ± 39	.002
Left-sided valve operation						
MV repair	45 (19.5)	47 (23.0)	.364	45 (21.2)	47 (21.6)	.919
MV replacement	182 (78.8)	157 (77.0)	.647	182 (75.8)	157 (78.4)	.522
AV repair	8 (3.5)	4 (2.0)	.392	8 (3.3)	4 (1.3)	.177
AV replacement	63 (27.3)	61 (29.9)	.544	63 (31.6)	61 (29.3)	.618
Concomitant procedure						
Arrhythmia surgery	130 (56.3)	152 (74.5)	<.001	130 (58.5)	152 (82.2)	<.001
Aorta surgery	11 (4.8)	16 (7.8)	.184	11 (7.0)	16 (6.0)	.666
CABG	3 (1.3)	7 (3.4)	.139	3 (0.9)	7 (3.2)	.081
Operative mortality	8 (3.5)	7 (3.4)	.986	8 (2.6)	7 (3.4)	.613
Postoperative morbidities						
LCOS	32 (13.9)	9 (4.4)	.001	32 (11.7)	9 (4.4)	.007
Respiratory complication	25 (10.8)	5 (2.5)	.001	25 (7.6)	5 (3.3)	.057
Acute kidney injury	13 (5.6)	10 (4.9)	.736	13 (4.0)	10 (3.8)	.886
Bleeding reoperation	14 (6.1)	8 (3.9)	.310	14 (4.5)	8 (5.1)	.772
Stroke	10 (4.3)	4 (2.0)	.184	10 (4.9)	4 (3.5)	.486
Mediastinitis	2 (0.9)	1 (0.5)	>.999	2 (1.5)	1 (0.4)	.261
Complete AV block	1 (0.4)	0 (0.0)	>.999	1 (1.2)	0 (0.0)	.127
Infective endocarditis	1 (0.4)	0 (0.0)	>.999	1 (0.3)	0 (0.0)	.478

Values are presented as mean ± standard deviation for continuous data or n (%). *CPB*, Cardiopulmonary bypass; *ACC*, aortic crossclamp; *MV*, mitral valve; *AV*, aortic valve; *CABG*, coronary artery bypass grafting; *LCOS*, low cardiac output syndrome; *AV*, atrioventricular.

TABLE E4. Etiologies of left-sided valve lesion stratified by left-sided valve operation

Operation	Group D (n = 231)	Group R (n = 204)
MV repair	45	47
Degenerative	40 (88.9)	46 (97.9)
Rheumatic	4 (8.9)	1 (2.1)
Congenital	1 (2.2)	0 (0.0)
MV replacement	182	157
Degenerative	19 (10.4)	11 (7.0)
Rheumatic	122 (67.0)	137 (87.3)
Prosthetic valve failure	40 (22.0)	9 (5.7)
Others	1 (0.5)	0 (0.0)
AV repair	8	4
Degenerative	1 (12.5)	1 (25.0)
Rheumatic	7 (87.5)	1 (25.0)
Others	0 (0.0)	2 (50.0)
AV replacement	63	61
Degenerative	5 (7.9)	9 (14.8)
Rheumatic	44 (69.8)	44 (72.1)
Prosthetic valve failure	12 (19.0)	1 (1.6)
Bicuspid	2 (3.2)	7 (11.5)

Values are presented as n or n (%). *MV*, Mitral valve; *AV*, aortic valve.

TABLE E5. Multivariable subdistribution hazard model regression for tricuspid regurgitation (TR) recurrence in the subgroup whose dominant left-sided valvular lesion was the mitral valve

	Univariate analysis		Multivariable analysis	
Variable	*P* value	Hazard ratio (95% Confidence interval)	*P* value	Hazard ratio (95% Confidence interval)
Female vs male	.568	0.77 (0.32-1.86)	–	–
Age (y)	.008	1.04 (1.01-1.07)	.130	1.03 (0.99-1.08)
BMI	.237	0.92 (0.80-1.06)	–	–
BSA (m^2)	.047	0.06 (0.00-0.97)	.263	0.18 (0.01-3.60)
Diabetes mellitus	.196	0.52 (0.19-1.40)	–	–
Hypertension	.790	1.16 (0.40-3.38)	–	–
COPD	<.001	0.14 (0.05-0.41)	.144	0.42 (0.13-1.35)
History of stroke	.685	0.78 (0.23-2.63)	–	–
CKD	.358	0.67 (0.29-1.56)	–	–
CAD	.507	0.50 (0.07-3.82)	–	–
Atrial fibrillation	.204	0.27 (0.04-2.02)	–	–
Reoperation	.193	2.61 (0.62-11.11)	–	–
NYHA class	.193	0.58 (0.26-1.32)	–	–
LVEDD (mm)*	.040	0.95 (0.90-1.00)	.054	0.95 (0.91-1.00)
LVESD (mm)*	.063	0.94 (0.89-1.00)	–	–
LVEF (%)*	.977	1.00 (0.95-1.05)	–	–
LA size (mm)*	.748	1.00 (0.98-1.03)	–	–
PASP (mmHg)*	.582	1.01 (0.98-1.03)	–	–
TR grade*	.001	1.72 (1.26-2.37)	.250	1.24 (0.86-1.80)
TAP method	.001	7.57 (2.26-25.33)	.004	6.28 (1.81-21.80)
Repair vs replacement †	.023	2.53 (1.14-5.65)	.021	2.69 (1.16-6.23)

Missing values refer to hazard ratios of yes (vs no) for categorical variables or hazard ratios of a 1-unit change in TR grade and continuous variables. *BMI*, Body mass index; *BSA*, body surface area; *COPD*, chronic obstructive pulmonary disease; *CKD*, chronic kidney disease; *CAD*, coronary artery disease; *NYHA*, New York Heart Association; *LVEDD*, left ventricular end diastolic dimension; *LVESD*, left ventricular end systolic dimension; *LVEF*, left ventricular ejection fraction; *LA*, left atrium; *PASP*, pulmonary arterial systolic pressure; *TR*, tricuspid regurgitation; *TAP*, tricuspid annuloplasty. *Preoperative measurements. †Mitral valve repair versus replacement.