# Long-term Fate of Dilated Ascending Aorta after Aortic Valve Replacement for Bicuspid Versus Tricuspid Aortic Valve Disease

Min-Seok Kim, MD, PhD, MSc, Jung Hwan Kim, MD, Seung Hyun Lee, MD, PhD, Sak Lee, MD, PhD, Young-Nam Youn, MD, PhD, Kyung-Jong Yoo, MD, PhD, and Hyun-Chel Joo, MD*

**We compared the long-term outcomes and difference in dilatation rates of the ascending aorta after aortic valve (AV) replacement (AVR) between bicuspid and tricuspid AV patients, and evaluated risk factors associated with ascending aorta dilatation and aortic events during the follow-up. Of 1,127 patients who underwent AVR from 1995 to 2015, 259 patients with a dilated ascending aorta (≥40 mm in diameter) were included. The patients were divided into those with bicuspid (group bicuspid aortic valve [BAV], n = 105) and with tricuspid (group tricuspid aortic valve [TAV], n = 154) AV, and a propensity score-matched analysis was performed to match 98 patients in each group. The differences in the dilation rate of the ascending aorta and long-term outcomes were analyzed. Risk factors for ascending aorta dilatation, mortality, and aortic events were identified. Follow-up was completed in 100% of patients with a median follow-up duration of 106.1 [68.8, 163.0] months. The early clinical outcomes and dilation rate of the ascending aorta were similar between the groups. Overall survivals up to 15 years postoperatively were similar between groups BAV and TAV (p = 0.223). Aortic events occurred in 6 patients (groups BAV vs TAV, 2 vs 4;p = 0.678). Preoperative ascending aorta diameter showed a linear relationship with the dilatation rate of ascending aorta (p <0.001) and was related to progressive aortic dilatation and aortic events (odds ratio: 1.25, p <0.001 and hazard ratio = 1.56, p <0.001, respectively). In conclusion, the long-term outcomes and ascending aorta dilatation rate were similar between the BAV and TAV patients up to 15 years after AVR. Bicuspid AV was not a risk factor of mortality or aortic events.**
 **(Am J Cardiol 2020;129:53–59)**

The bicuspid aortic valve (AV) has a prevalence of 1.3% in the general population, and is known to be related to aortic stenosis, regurgitation, and aortic aneurysm.[1] Aortopathy occurs in about 50% of patients with bicuspid AV, and the incidence of ascending aortic dissection in patients with bicuspid AV is estimated to be approximately 6 to 8 times higher than that in the general population.[2,3] Hemodynamic and genetic components have been suggested to be related to the pathogenesis of aortic dilatation in bicuspid AV patients.[4–6] Progressive dilatation of the ascending aorta was also reported after AV replacement (AVR) and aggressive replacement of the ascending aorta was suggested in bicuspid AV patients at the time of AVR.[7–11] By contrast, others have demonstrated favorable survival rates, freedom from aortic events, or ascending aorta dilation in bicuspid AV patients after AVR.[12–17] The aims of the present study were (1) to compare the long-term outcomes and assess the difference in the dilatation rates of the ascending aorta after AVR between the patients with bicuspid and tricuspid AV, and (2) to evaluate risk factors associated with ascending aorta dilatation and aortic events during the postoperative follow-up.

## Methods

The study protocol was reviewed by the Institutional Review Board and was approved as a minimal-risk retrospective study (approval number: 4-2019-0410) that did not require individual consent based on the institutional guidelines for waiving consent.

Of 1,127 patients who underwent AVR without other valve surgery from January 1995 to December 2015, 259 patients who had a dilated ascending aorta (40 to 55 mm in maximal diameter, as assessed by preoperative transthoracic 2-dimensional echocardiography) were studied. The diameter of ascending aorta was also measured by contrast-enhanced computed tomography (CT) preoperatively if the maximal diameter of ascending aorta was measured as ≥40 mm by preoperative transthoracic 2-dimensional echocardiography. Patients with a maximal aortic diameter >55 mm were not included because concomitant procedures on the ascending aorta were also performed in those patients. Three hundred thirty patients who underwent concomitant procedures on the ascending aorta (ascending aorta replacement or wrapping with prosthetic vascular graft; n = 239), underwent aortic root replacement (n = 89), and had connective tissue disease such as Marfan or Ehlers-

Division of Cardiovascular Surgery, Severance Cardiovascular Hospital, Yonsei University College of Medicine, Seoul, Korea. Manuscript received March 17, 2020; revised manuscript received and accepted May 18, 2020.

*Corresponding author: Tel: 82-2-2228-8489; fax: 82-2-313-2992.
*E-mail address:* vietcomm@yuhs.ac (H.-C. Joo).



https://doi.org/10.1016/j.amjcard.2020.05.026

Danlos syndrome (n = 2) were excluded. The other 538 patients who had an ascending aorta <40 mm in maximal diameter were also excluded. However, 35 patients who underwent other concomitant surgical procedures, such as coronary artery bypass grafting (n = 29), ventricular septal defect closure (n = 2), septal myectomy (n = 2), coronary arteriovenous fistula closure (n = 1), and surgery for atrial fibrillation (n = 1) were included. The patients were divided into 2 groups based on the intraoperative description of valve morphology by the surgeon: patients with bicuspid AV (group bicuspid aortic valve [BAV], n = 105) and tricuspid AV (group tricuspid aortic valve [TAV], n = 154) patients. Propensity score-matched analysis based on 14 variables was performed to adjust for differences in the preoperative characteristics, and 98 patients in each group were extracted by 1:1 matching (Figure 1). Before matching, group BAV patients were younger than group TAV patients. After matching, however, no significant differences were found in the demographic data between the matched groups, and all covariates were well balanced between the groups with a standardized mean difference ≤10% (Supplementary Table S1).

Patients underwent regular postoperative follow-up examinations at the outpatient clinic at 5- to 6-month intervals, and their survival status or the presence of aortic and cardiovascular events was collected by reviewing electronic medical records. In addition, the data for vital statistics and death from cardiovascular diseases were obtained from death certificates available at Statistics Korea, a central organization for statistics under the Ministry of Strategy and Finance. The clinical and echocardiographic follow-up examinations were closed on June 30, 2019. The follow-up data were complete in 100% (259/259) of patients, with a median follow-up duration of 106.1[68.8, 163.0] months. Operative death was defined as death occurring within 30 days after AVR or during the same hospital stay. Cardiac death was defined as any death related to cardiac events, including sudden death during the follow-up. An aortic event was defined as the occurrence of aortic dissection or an operation on the ascending aorta during the follow-up.

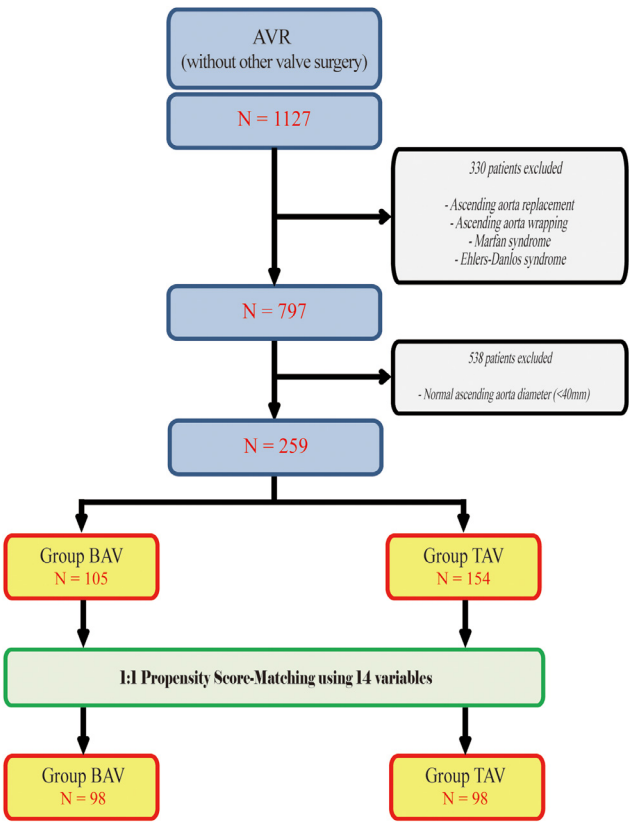


Figure 1. Summary flow diagram of patients.

The preoperative echocardiographic data within 3 months prior to surgery and last postoperative echocardiographic follow-up data of the patients were analyzed. The last follow-up echocardiograms were performed at a median of 79.2[38.7, 139.0] months postoperatively. Multiple echocardiographic measurements of the maximal diameter of the proximal ascending aorta were performed in systole using the parasternal long-axis view, and the maximal diameter was used in the analysis. The body surface area (BSA)-indexed diameter of the ascending aorta (mm/$m^2$) and height-indexed diameter of the ascending aorta (mm/m) were calculated as suggested by previous studies.[18,19] The dilatation rate of the ascending aorta was calculated as follows: dividing the differences between the preoperative and last follow-up ascending aorta diameters by the follow-up duration (mm/months). The patient was regarded as "a progressive dilator" if the ascending aorta diameter increased at the last follow-up echocardiogram at least 6 months after surgery compared with the preoperative value.

Statistical analysis was performed using R software, version 3.6.0. Continuous data were expressed as mean ± standard deviation for normally distributed variables or as medians [interquartile range] for non-normally distributed variables according to the Shapiro-Wilk test, and categoric data were expressed as counts (percentages). For propensity score-matching, 14 variables—sex, age, body mass index, atrial fibrillation, hypertension, chronic renal failure, diabetes mellitus, chronic obstructive pulmonary disease, peripheral vascular obstructive disease, stroke history, coronary artery disease, New York Heart Association classifications, smoking, and left ventricular dysfunction (left ventricular ejection fraction <0.35)—were used. Propensity score-matching analysis was performed using R software (MatchIt package), and nearest neighbor matching with caliper size of 0.1 was used to match the groups in a 1:1 manner. Comparisons between continuous variables were made using Student's *t* test for normally distributed data or the Wilcoxon rank-sum test for non-normally distributed data. Categoric variables were compared using Chi-squared test. When ≥20% of the expected counts were ≤5, Fisher's exact test was used. McNemar test and paired *t* test were used for the comparison of the matched data. Logistic regression analysis was performed to identify the variables associated with progressive dilators. Overall survival, freedom from cardiac death and aortic events were analyzed using Kaplan-Meier survival curves, and comparisons between the groups were performed using the log-rank test. The Cox proportional hazard model was used to identify risk factors that affect the long-term survival and aortic events. Variables that achieved p <0.05 in the univariable analysis were

entered into the multivariable analysis. Receiver-operating characteristic (ROC) curve analysis of the preoperative ascending aorta diameter for the occurrence of aortic events was performed, and optimal cutoff values and areas under the curve were identified (Epi package, pROC package).

## Results

One operative mortality occurred with no intergroup differences between the matched groups (p >0.999). Postoperative complications, including bleeding reoperations, acute renal failure, stroke, and respiratory complications, were similar between the groups. The types of valve used (p = 0.631) and patient-prosthesis mismatch (defined as an indexed effective orifice area ≤0.85 $cm^2/m^2$; p >0.999) were not different between the matched groups. Concomitant surgical procedures were performed in 35 patients without a significant intergroup difference (p = 0.292). The preoperative diameter of the ascending aorta (p = 0.910) and the dilatation rate of the ascending aorta during the follow-up (p = 0.477) showed no difference between the matched groups (Table 1, Figure 2). Among the variables, the preoperative diameter of the ascending aorta was associated with progressive aortic dilation (odds ratio: 1.25; 95% confidence interval [CI]: 1.13 to 1.41; p <0.001) and showed a linear relationship with the growth rate of the ascending aorta (p <0.001; Supplementary Figure S1). Bicuspid AV was not associated with progressive aortic dilation (odds ratio: 1.24; 95% CI: 0.73 to 2.12; p = 0.429; Table 2).

All-cause mortalities occurred in 40 patients (groups BAV vs TAV: 12 vs 28, respectively), including 6 cardiac deaths (groups BAV vs TAV: 2 vs 4, respectively), during the follow-up period. There were 6 aortic events during the follow-up (groups BAV vs TAV: 2 vs 4, respectively): scheduled operations on the ascending aorta due to progressive aortic dilatation (n = 3; groups BAV vs TAV: 1 vs 2, respectively), aortic dissection (n = 2; group TAV), and dilated ascending aorta replacement during redo-AVR (n = 1; group BAV). The overall survival at postoperative 5, 10, and 15 years were 97.1%, 91.7%, and 81.4%, respectively, in group BAV, and 95.4%, 86.5%, and 74.2%, respectively, in group TAV. Freedom from cardiac death at postoperative 5, 10, and 15 years were 99.0%, 99.0%, and 96.2%, respectively, in group BAV, and 99.2%, 99.2%, and

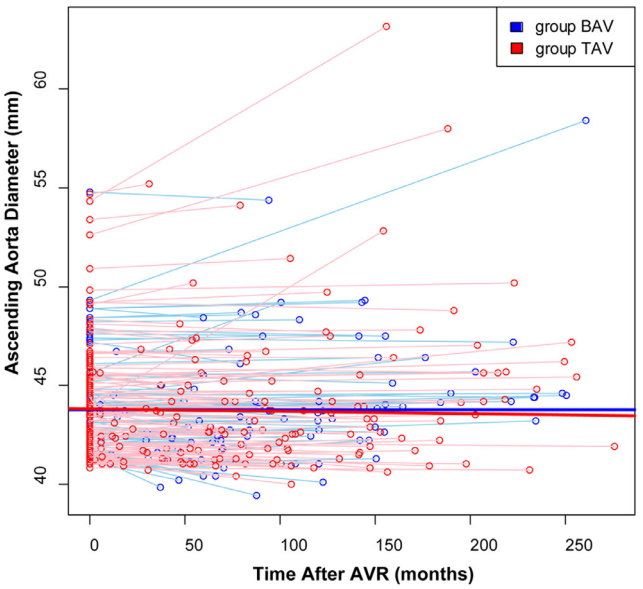


Figure 2. Changes in the ascending aorta dimeter during the follow-up between the BAV and TAV groups.

Table 1
Comparison of the operative data and postoperative results

| | All study patients | | | Propensity score-matched patients | | |
|---|---|---|---|---|---|---|
| | group BAV (n = 105) | group TAV (n = 154) | *P* | group BAV (n = 98) | group TAV (n = 98) | *P* |
| Operative data | | | | | | |
| Operative mortality | 0 | 1 (0.6%) | >.999 | 0 | 1 (1.0%) | >.999 |
| Type of artificial valve | | | .022 | | | .631 |
| Mechanical | 78 (74.3%) | 92 (59.7%) | | 73 (74.5%) | 69 (70.4%) | |
| Bioprosthetic | 27 (25.7%) | 62 (40.3%) | | 25 (25.5%) | 29 (29.6%) | |
| Patient-prosthesis mismatch | 21 (20.0%) | 32 (20.8%) | >.999 | 20 (20.4%) | 19 (19.4%) | >.999 |
| Concomitant operation | 12 (11.4%) | 23 (14.9%) | .532 | 10 (10.2%) | 16 (16.3%) | .292 |
| CPB time (minutes) | 100.0 [86.0, 124.0] | 101.5 [84.0, 126.0] | .866 | 99.5 [85.0, 124.0] | 102.0 [85.0, 130.0] | .901 |
| ACC time (minutes) | 72.0 [64.0, 91.0] | 70.5 [60.0, 90.0] | .303 | 72.0 [64.0, 92.0] | 71.0 [60.0, 95.0] | .535 |
| Postoperative complications | | | | | | |
| Bleeding reoperation | 0 | 3 (1.9%) | .397 | 0 | 2 (2.0%) | .477 |
| ARF | 1 (1.0%) | 1 (0.6%) | >.999 | 1 (1.0%) | 1 (1.0%) | >.999 |
| Stroke | 3 (2.9%) | 4 (2.6%) | >.999 | 3 (3.1%) | 3 (3.1%) | >.999 |
| Respiratory complications) | 0 | 1 (0.6%) | >.999 | 0 | 0 | >.999 |
| Follow-up outcomes | | | | | | |
| Growth rate of diameter of ascending aorta (millimeters/month) | -0.003 ± 0.0154 | -0.025 ± 0.1922 | .408 | -0.004 ± 0.0153 | -0.036 ± 0.2392 | .477 |
| Progressive dilators | 41/95 (43.2%) | 52/138 (37.7%) | .482 | 36/89 (40.4%) | 34/92 (37.0%) | .742 |

BAV, bicuspid aortic valve; BMI, body mass index; BSA, body surface area; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; TAV, tricuspid aortic valve.

Table 2
Univariable logistic regression analysis for the dilation of the ascending aorta diameter ("progressive dilators")

| Variables | Odds Ratio (95% CI) | *P* |
|---|---|---|
| Male sex | 0.765 (0.450−1.298) | .320 |
| Age | 0.979 (0.957−1.002) | .072 |
| BSA | 0.470 (0.106−2.024) | .314 |
| BMI | 1.022 (0.945−1.106) | .588 |
| Hypertension | 0.871 (0.512−1.475) | .608 |
| Smoking | 0.880 (0.496−1.545) | .659 |
| Bicuspid aortic valve | 1.256 (0.737−2.140) | .402 |
| Preoperative AS | 1.083 (0.640−1.837) | .766 |
| Preoperative AR | 1.134 (0.662−1.939) | .645 |
| Preoperative AS severity | 0.996 (0.826−1.203) | .968 |
| Preoperative AR severity | 0.955 (0.797−1.144) | .618 |
| Patient-prosthesis mismatch | 1.201 (0.620−2.302) | .582 |
| Mechanical prosthetic valve | 1.151 (0.660−2.030) | .622 |
| Preoperative ascending aorta diameter | 1.253 (1.125−1.409) | <.001 |

AR = aortic regurgitation; AS = aortic stenosis; BMI = body mass index; BSA = body surface area; NYHA = New York Heart Association.

96.7%, respectively, in group TAV. Freedom from aortic event at postoperative 5, 10, and 15 years were 100.0%, 98.1%, and 98.1%, respectively, in group BAV, and 99.3%, 99.3%, and 95.0%, respectively, in group TAV. No differences were found in the overall survival, freedom from cardiac deaths and aortic events between groups BAV and TAV and between the matched groups (Figure 3).

Multivariable analysis by the Cox proportional hazard model revealed age to be a significant predictor of all-cause mortality (hazard ratio [HR]: 1.08; 95% CI: 1.03 to 1.12; p <0.001), and bicuspid AV was not analyzed to be a risk factor of mortality (HR: 0.66; 95% CI: 0.33 to 1.30; p = 0.226; Table 3). The preoperative (HR: 1.56; 95% CI: 1.26 to 1.93; p <0.001), preoperative BSA-indexed (HR: 1.38; 95% CI: 1.11 to 1.71; p = 0.003), and preoperative height-indexed (HR: 1.63; 95% CI: 1.26 to 2.11; p <0.001) ascending aorta diameters were predictors of aortic events. The bicuspid AV was not a risk factor for aortic events (HR: 0.70; 95% CI: 0.12 to 3.88; p = 0.680). Regarding aortic dissection among the aortic events, BSA-indexed (HR: 1.44; 95% CI: 1.02 to 2.04; p = 0.039) and height-indexed ascending aorta diameters (HR: 2.20; 95% CI: 1.19 to 4.05; p = 0.012), rather than the ascending aorta diameter, were analyzed to be predictors of aortic events (Table 4). The cutoff values of the preoperative, preoperative BSA-indexed, and preoperative height-indexed ascending aorta diameters for postoperative aortic events were 45.5 mm (sensitivity: 83.3%; specificity: 82.6%), 27.85 mm/m$^2$ (sensitivity: 83.3%; specificity: 72.7%), and 28.85 mm/m$^2$ (sensitivity: 83.3%; specificity: 84.2%), respectively. The preoperative, preoperative BSA-indexed, and preoperative height-indexed ascending aorta diameters were significant factors predicting postoperative aortic events with areas under the curve of 0.908 (p <0.001), 0.808 (p =0.010), and 0.814 (p = 0.009), respectively (Supplementary Figure S2).

## Discussion

The present study demonstrated four main findings. First, patients with bicuspid and tricuspid AV showed similar ascending aorta dilation rates at a median follow-up of 79.2 months after AVR. Second, patients with bicuspid and tricuspid AV showed similar long-term clinical outcomes up to 15 years postoperatively in terms of overall survival, freedom from cardiac death and aortic events. Third, the preoperative and preoperative indexed ascending aorta diameters were risk factors for aortic events during the follow-up. Fourth, the bicuspid AV was not a risk factor for survival or aortic events after AVR in patients with ascending aorta dilatation.

The current guidelines recommend ascending aorta aneurysms of bicuspid AV patients to be treated similarly to those of tricuspid AV patients.[20,21] However, recent studies are still reporting progressive dilatation of ascending aorta aneurysm in bicuspid AV patients after AVR. The study by Girdauskas et al included 325 isolated AVR patients and showed similar freedom from aortic events between bicuspid and tricuspid AV patients with aortic stenosis and ascending aorta dilatation.[22] However, in their subsequent study which included 56 patients with bicuspid AV insufficiency and a root diameter of 40 to 50 mm, Girdauskas et al reported progressive dilatation of the aortic root and risk of aortic events after isolated AVR and recommended aggressive aortic surgery in this "root phenotype" bicuspid AV patients.[11] Another meta-analysis demonstrated a 10-fold higher risk of aortic dissection after AVR in bicuspid AV insufficiency patients than in bicuspid AV stenosis patients.[9] The present study included 105 bicuspid and 154 tricuspid AV patients with dilated ascending aorta and showed similar ascending aorta dilation rates at a median follow-up of 6.5 years after AVR before and after propensity score-matching. Although no significant increase in the mean ascending aorta diameter was demonstrated in the current study, the preoperative diameter of the ascending aorta was a factor related to the ascending aorta dilation and a linear relationship was found between the preoperative ascending aorta diameter and dilation rate of the ascending aorta.

The present study demonstrated no statistical differences in overall survival, cardiac mortality-free survival and freedom from aortic events up to 15 years postoperatively between the 2 groups as well as before and after propensity score-matching. In addition, the bicuspid AV and preoperative AV insufficiency were not related to aortic events such as aortic dissection. The preoperative and preoperative indexed ascending aorta diameters were related to the aortic events, and the preoperative indexed ascending aorta diameter was only related to aortic dissection. Previous studies have emphasized indexed aortic dimensions using either BSA or height for the risk evaluation because using the absolute ascending aorta diameter in the risk stratification of aortic events may have limitations when the patient's size or height is not considered.[19,23,24] The present study also showed that BSA- and height-indexed ascending aorta diameters, rather than the absolute ascending aorta diameter, were significant factors related to aortic dissections during the follow-up. Although the incidence of aortic events was low in the present study, ROC curve analysis revealed that the cutoff value of the preoperative ascending aorta diameter for aortic event occurrence was 45.5 mm, which

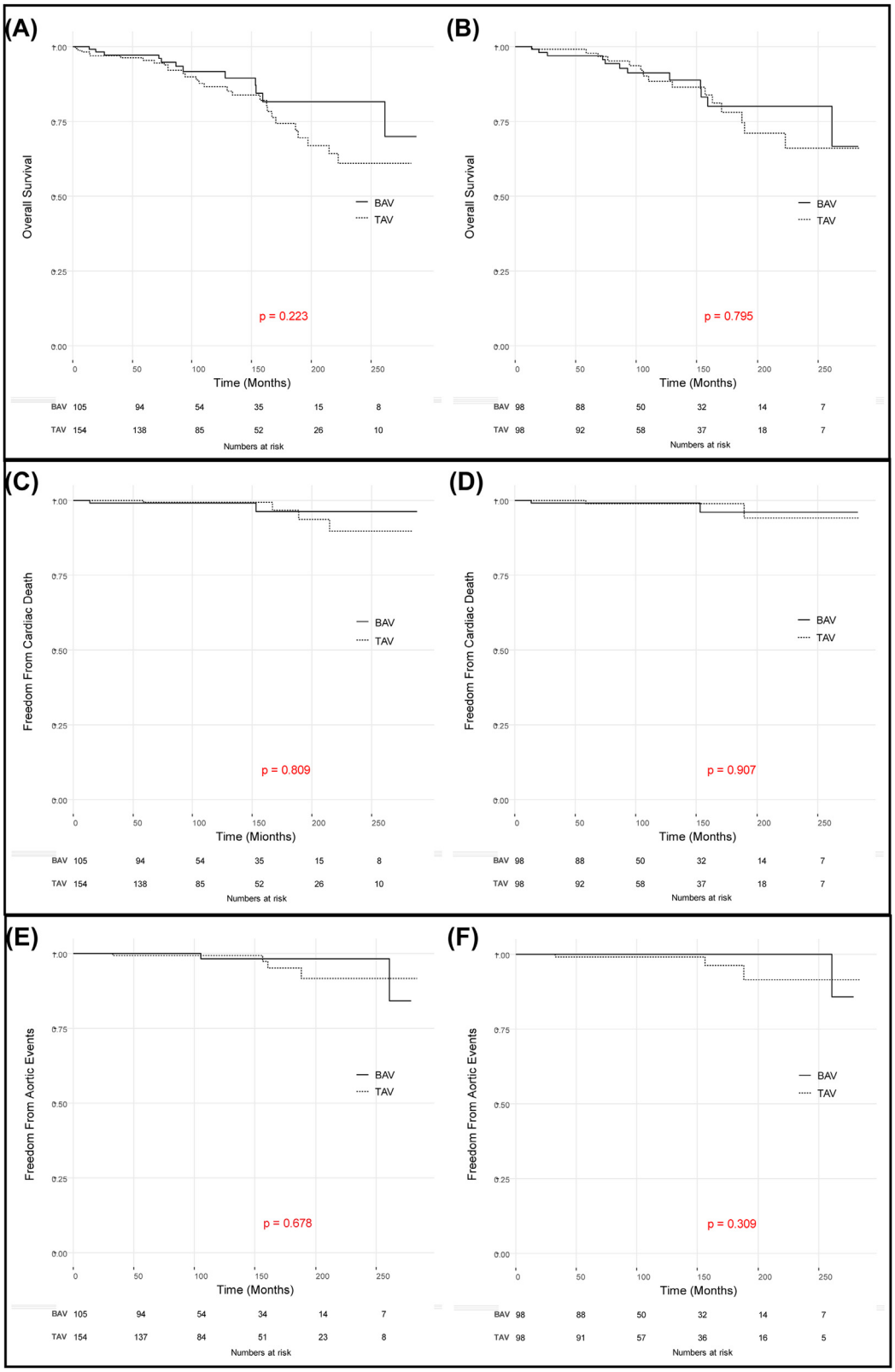


Figure 3. Comparison of the (A) overall survival, (C) cardiac mortality-free survival and (E) freedom from aortic events between the BAV and TAV groups in all study patients. Comparison of the (B) overall survival, (D) cardiac mortality-free survival and (F) freedom from aortic events between the matched BAV and TAV groups.

Table 3
Univariable and multivariable predictors of all-cause mortality

| | Univariable analysis | | Multivariable analysis | |
|---|---|---|---|---|
| Variables | HR (95% CI) | P | HR (95% CI) | P |
| Male sex | 1.21 (0.64−2.29) | .564 | | |
| Age | 1.09 (1.05−1.14) | <.001 | 1.08 (1.03−1.12) | <.001 |
| BMI | 1.05 (0.95−1.16) | .334 | | |
| Hypertension | 2.03 (1.08−3.83) | .028 | 1.21 (0.60−2.41) | .595 |
| Atrial fibrillation | 1.65 (0.58−4.65) | .345 | | |
| Chronic renal failure | 2.28 (0.80−6.46) | .122 | | |
| Diabetes mellitus | 3.14 (1.34−7.39) | .009 | 2.22 (0.91−5.40) | .079 |
| Chronic obstructive pulmonary disease | 1.51 (0.35−6.46) | .577 | | |
| History of stroke | 1.94 (0.59−6.32) | .272 | | |
| Coronary artery disease | 2.59 (1.31−5.15) | .006 | 1.34 (0.64−2.80) | .441 |
| Peripheral vascular obstructive disease | 3.93 (1.19−12.97) | .025 | 1.54 (0.44−5.43) | .504 |
| Smoking | 1.74 (0.93−3.27) | .085 | | |
| NYHA class | 2.02 (1.31−3.10) | .001 | 1.43 (0.87−2.36) | .159 |
| Severity of preoperative AS | 0.99 (0.80−1.22) | .907 | | |
| Severity of preoperative AR | 0.94 (0.75−1.16) | .556 | | |
| Patient-prosthesis mismatch | 1.50 (0.76−2.96) | .248 | | |
| Bicuspid aortic valve | 0.66 (0.33−1.30) | .226 | | |
| Preoperative ascending aorta diameter | 1.05 (0.95−1.16) | .315 | | |

AR = aortic regurgitation; AS = aortic stenosis; BMI = body mass index; BSA = body surface area; NYHA = New York Heart Association.

was similar to the threshold value for ascending aorta replacement suggested by the current guidelines.[20,21]

The present study has limitations that must be recognized. First, the present study was not performed in a prospective randomized manner, although propensity score-matching was performed to overcome the limitations of a retrospective study. Second, the sample size of this study was too small to conclude the usefulness of the indexed ascending aorta diameter in predicting postoperative outcomes. Larger studies with a long-term follow-up may be needed. Third, the follow-up and measurement of the ascending aorta were performed by echocardiography, rather than CT, although transthoracic echocardiography is proven to be a feasible and accurate technique.[25] If the preoperative ascending aorta diameter measured by transthoracic echocardiography is ≥40 mm in maximal diameter, contrast-enhanced CT was also performed to reduce the risk of over- or under-estimation. The difference in diameter was used as one of the major parameters to minimize bias caused by using echocardiography rather than CT as a diagnostic tool. Fourth, the bicuspid AV phenotype and aortopathy types were not included in the analysis, although previous studies reported correlations of the bicuspid AV phenotype and aortopathy types with postoperative outcomes.[26,27]

In conclusion, the long-term outcomes and ascending aorta dilation rates were similar between bicuspid and tricuspid AV patients up to 15 years after AVR. Bicuspid AV was not a risk factor of mortality or aortic events during the follow-up. Adherence to the current guidelines seems adequate, and aggressive surgical treatment of the dilated ascending aorta in bicuspid AV patients may not be indicated.

Table 4
Univariable predictors of aortic events and aortic dissections

| | Aortic Events | | Aortic Dissections | |
|---|---|---|---|---|
| Variables | HR (95% CI) | *P* | HR (95% CI) | *P* |
| Male sex | 1.34 (0.25−7.36) | .733 | 0.76 (0.05−12.08) | .843 |
| Age | 0.95 (0.89−1.01) | .105 | 0.99 (0.88−1.11) | .870 |
| BMI | 0.98 (0.75−1.28) | .866 | 1.57 (0.98−2.51) | .063 |
| Hypertension | 1.08 (0.19−6.08) | .927 | n.c. | >.999 |
| Atrial Fibrillation | 3.37 (0.38−29.51) | .273 | n.c. | >.999 |
| Smoking | 2.32 (0.46−11.66) | .307 | n.c. | >.999 |
| NYHA class | 0.36 (0.11−1.15) | .085 | n.c. | >.999 |
| Preoperative AS | 1.08 (0.21−5.53) | .925 | n.c. | >.999 |
| Preoperative AR | 1.57 (0.30−8.17) | .593 | n.c. | >.999 |
| Severity of preoperative AS | 0.97 (0.55−1.70) | .916 | n.c. | >.999 |
| Severity of preoperative AR | 0.84 (0.47−1.49) | .555 | n.c. | >.999 |
| Bicuspid aortic valve | 0.70 (0.12−3.88) | .680 | n.c. | >.999 |
| Preoperative ascending aorta diameter | 1.56 (1.26−1.93) | <.001 | 3.49 (0.36−33.44) | .278 |
| BSA-indexed preoperative ascending aorta diameter | 1.38 (1.11−1.71) | .003 | 1.44 (1.02−2.04) | .039 |
| Height-indexed preoperative ascending aorta diameter | 1.63 (1.26−2.11) | <.001 | 2.20 (1.19−4.05) | .012 |

AR = aortic regurgitation; AS = aortic stenosis; BMI = body mass index; BSA = body surface area; NYHA = New York Heart Association.

## Conflict of Interests

None.

## Acknowledgemnts

None.

## Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amjcard.2020.05.026.

1. Verma S, Siu SC. Aortic dilatation in patients with bicuspid aortic valve. *N Engl J Med* 2014;370:1920–1929.
2. Michelena HI, Khanna AD, Mahoney D, Margaryan E, Topilsky Y, Suri RM, Eidem B, Edwards WD, Sundt TM III, Enriquez-Sarano M. Incidence of aortic complications in patients with bicuspid aortic valves. *JAMA* 2011;306:1104–1112.
3. Sievers H-H, Sievers HL. Aortopathy in bicuspid aortic valve disease-genes or hemodynamics? or Scylla and Charybdis? *Eur J Cardiothorac Surg* 2011;39:803–804.
4. Hope MD, Hope TA, Meadows AK, Ordovas KG, Urbania TH, Alley MT, Higgins CB. Bicuspid aortic valve: four-dimensional MR evaluation of ascending aortic systolic flow patterns. *Radiology* 2010;255:53–61.
5. Tadros TM, Klein MD, Shapira OM. Ascending aortic dilatation associated with bicuspid aortic valve: pathophysiology, molecular biology, and clinical implications. *Circulation* 2009;119:880–890.
6. Tobin SW, Alibhai FJ, Lee MM, Yeganeh A, Wu J, Li S-H, Guo J, Tsang K, Tumiati L, Rocha R, Butany J, Yau TM, Ouzounian M, David TE, Weisel RD, Li RK. Novel mediators of aneurysm progression in bicuspid aortic valve disease. *J Mol Cell Cardiol* 2019;132:71–83.
7. Andrus BW, O'Rourke DJ, Dacey LJ, Palac RT. Stability of ascending aortic dilatation following aortic valve replacement. *Circulation* 2003;108:295–299. [suppl II]:II-.
8. Yasuda H, Nakatani S, Stugaard M, Tsujita-Kuroda Y, Bando K, Kobayashi J, Yamagishi M, Kitakaze M, Kitamura S, Miyatake K. Failure to prevent progressive dilation of ascending aorta by aortic valve replacement in patients with bicuspid aortic valve: comparison with tricuspid aortic valve. *Circulation* 2003;108:291–294. [suppl II]:II-.
9. Girdauskas E, Rouman M, Disha K, Espinoza A, Misfeld M, Borger MA, Kuntze T. Aortic dissection after previous aortic valve replacement for bicuspid aortic valve disease. *J Am Coll Cardiol* 2015;66:1409–1411.
10. Borger MA, Preston M, Ivanov J, Fedak PW, Davierwala P, Armstrong S, David TE. Should the ascending aorta be replaced more frequently in patients with bicuspid aortic valve disease. *J Thorac Cardiovasc Surg* 2004;128:677–683.
11. Girdauskas E, Disha K, Rouman M, Espinoza A, Borger MA, Kuntze T. Aortic events after isolated aortic valve replacement for bicuspid aortic valve root phenotype: echocardiographic follow-up study. *Eur J Cardiothorac Surg* 2015;48:e71–e76.
12. McKellar SH, Michelena HI, Li Z, Schaff HV, Sundt TM III. Long-term risk of aortic events following aortic valve replacement in patients with bicuspid aortic valves. *Am J Cardiol* 2010;106:1626–1633.
13. Abdulkareem N, Soppa G, Jones S, Valencia O, Smelt J, Jahangiri M. Dilatation of the remaining aorta after aortic valve or aortic root replacement in patients with bicuspid aortic valve: A 5-year follow-up. *Ann Thorac Surg* 2013;96:43–49.
14. Charitos EI, Stierle U, Petersen M, Mohamed SA, Hanke T, Schmidtke C, Klotz S, Sievers HH. The fate of the bicuspid valve aortopathy after aortic valve replacement. *Eur J Cardiothorac Surg* 2014;45:e128–e135.
15. Disha K, Rouman M, Secknus M-A, Kuntze T, Girdauskas E. Are normal-sized ascending aortas at risk of late aortic events after aortic valve replacement for bicuspid aortic valve disease. *Int CardioVasc Thorac Surg* 2016;22:465–471.
16. Regeer MV, Versteegh MIM, Klautz RJM, Schalij MJ, Bax JJ, Marsan NA, Delgado V. Effect of aortic valve replacement on aortic root dilatation rate in patients with bicuspid and tricuspid aortic valves. *Ann Thorac Surg* 2016;102:1981–1987.
17. Kaneko T, Shekar P, Ivkovic V, Longford NT, Huang C-C, Sigurdsson MI, Neely RC, Yammine M, Ejiofor JI, Montiero Vieira V, Shahram JT, Habchi KM, Malzberg GW, Martin PS, Bloom J, Isselbacher EM, Muehlschlegel JD, Bicuspid Aortic Consortium, Sundt TM III, Body SC. Should the dilated ascending aorta be repaired at the time of bicuspid aortic valve replacement? *Eur J Cardiothorac Surg* 2018;53:560–568.
18. Biaggi P, Matthews F, Braun J, Rousson V, Kaufmann PA, Jenni R. Gender, age, and body surface area are the major determinants of ascending aorta dimensions in subjects with apparently normal echocardiograms. *J Am Soc Echocardiogr* 2009;22:720–725.
19. Zafar MA, Li Y, Rizzo JA, CharilaouP Saeyeldin A, Velasquez CA, Mansour AM, Bin Mahmood SU, Ma WG, Brownstein AJ, Tranquilli M, Dumfarth J, Theodoropoulos P, Thombre K, Tanweer M, Erben Y, Peterss S, Ziganshin BA, Elefteriades JA. Height alone, rather than body surface area, suffices for risk estimation in ascending aortic aneurysm. *J Thorac Cardiovasc Surg* 2018;155:1938–1950.
20. Hiratzka LF, Bakris GL, Beckman JA, Bersin RM, Carr VF, Jr Casey DE, Eagle KA, Hermann LK, Isselbacher EM, Kazerooni EA, Kouchoukos NT, Lytle BW, Milewicz DM, Reich DL, Sen S, Shinn JA, Svensson LG, Williams DM. 2010 ACCF/ AHA/ AATS/ ACR/ ASA/ SCA/ SCAI/ SIR/ STS/ SVM guidelines for the diagnosis and management of patients with thoracic aortic disease: a report of the American College of Cardiology Foundation/ American Heart Association Task Force on practice guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *Circulation* 2010;121:e266–e369.
21. Hiratzka LF, Creager MA, Isselbacher EM, Svensson LG, Nishimura RA, Bonow RO, Guyton RA, Sundt TM III, Halperin JL, Levine GN, Anderson JL, Albert NM, Al-khatib SM, Birtcher KK, Bozkurt B, Brindis RG, Cigarroa JE, Curtis LH, Fleisher LA, Gentile F, Gidding S, Hlatky MA, Ikonomidis J, Joglar J, Kovacs RJ, Ohman EM, Pressler SJ, Sellke FW, Shen WK, Wijeysundera DN. Surgery for aortic dilatation in patients with bicuspid aortic valves: a statement of clarification from the American College of Cardiology/ American Heart Association Task Force on clinical practice guidelines. *J Am Coll Cardiol* 2016;67:724–731.
22. Girdauskas E, Disha K, Borger MA, Kuntze T. Long-term prognosis of ascending aortic aneurysm after aortic valve replacement for bicuspid versus tricuspid aortic valve stenosis. *J Thorac Cardiovasc Surg* 2014;147:276–282.
23. Svensson LG, Kim KH, Lytle BW, Cosgrove DM. Relationship of aortic cross-sectional area to height ratio and the risk of aortic dissection in patients with bicuspid aortic valves. *J Thorac Cardiovasc Surg* 2003;126:892–893.
24. Davies RR, Gallo A, Coady MA, Tellides G, Botta DM, Burke B, Coe MP, Kopf GS, Elefteriades JA. Novel measurement of relative aortic size predicts rupture of thoracic aortic aneurysms. *Ann Thorac Surg* 2006;81:169–177.
25. Tamborini G, Galli CA, Maltagliati A, Andreini D, Pontone G, Quaglia C, Ballerini G, Pepi M. Comparison of feasibility and accuracy of transthoracic echocardiography versus computed tomography in patients with known ascending aortic aneurysm. *Am J Cardiol* 2006;98:966–969.
26. Corte Della A, Bancone C, Quarto C, Dialetto G, Covino FE, Scardone M, Caianiello G, Cotrufo M. Predictors of ascending aortic dilatation with bicuspid aortic valve: A wide spectrum of disease expression. *Eur J Cardiothorac Surg* 2007;31:397–404.
27. Sievers H-H, Stierle U, Mohamed SA, Hanke T, Richardt D, Schmidtke C, Charitos EI. Toward individualized management of the ascending aorta in bicuspid aortic valve surgery: The role of valve phenotype in 1362 patients. *Surgery* 2014;148:2072–2080.