Natural History of Ascending Aortic Aneurysms (40-50 mm): Impact of Bicuspid Aortic Valves

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Short Title: Bicuspid Valves and Aneurysms

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ABSTRACT:

Background: Growth of ascending aortic aneurysms in bicuspid aortic valve (BAV) patients is controversial.

Methods: To evaluate the natural history of medically treated ascending aortic aneurysms and the impact of BAV, 572 patients (104 pts BAV; 468 pts with tricuspid aortic valve(TAV) with 40-50mm ascending aortic aneurysms were followed prospectively in a dedicated thoracic aortic clinic.

Results: Patients with BAV were younger (BAV: 56.5±10.6 vs. TAV: 66.9±9.9; p<0.0001) and less high blood pressure (BAV:54.4% vs. TAV:69.2%; p=0.01). Maximal ascending aortic diameter was significantly larger in BAV vs. TAV patients (46.5±2.3 vs. 45.2±3.0; p<0.0001). Mean follow-up was 3.9±2.5 years. Significantly more patients were operated during follow-up for the ascending aorta or the aortic valve in the BAV group (BAV:32.7% vs. TAV:7.3%; p<0.0001). Only one patient with TAV was operated emergently for an acute aortic syndrome. Operative mortality was 0% and overall mortality was 10.3%. Five- and ten-year freedom from ascending aortic aneurysm progression >2 mm was comparable for both groups BAV vs. TAV (86.5% vs. 83.9%) and (36.0% vs. 29.4%); (log rank=0.51). Five- and ten-year survival for both groups was BAV vs TAV (96.7% vs 96.6%) and (91.2% vs 90.8%) years (p=0.94).

Conclusions: Medically treated 40-50mm ascending aortic aneurysms show slow growth rate comparable for BAV and TAV patients. Freedom from acute aortic-related events and survival are very high in both BAV and TAV patients.

INTRODUCTION:

Bicuspid aortic valve (BAV) is the most common congenital heart anomaly reported in 1-2% of the general population[1]. In patients with BAV, the prevalence of dilatation of the ascending aorta is as high as 50%[2].

Although BAV patients are more prone to aortopathy and its potential complications, the impact on the growth rate of ascending aortic aneurysms remains controversial in the current literature. Management is equivocal owing to a lack of data on its natural history, as reflected in the wavering guidelines published on the aortic diameter thresholds proposed for surgical resection. In the early 2000s, guidelines recommended a more aggressive threshold to aortic replacement (5 cm and 4.5 cm in centers of expertise) [3-5], largely due to a suggested high prevalence and accelerated growth rate of aortic aneurysms in comparison to TAV as well as studies demonstrating a high incidence of aortic dissection in BAV patients with aortic diameters less than 5.0 cm[6-9]. In contrast, the 2014 ACC/AHA guidelines suggested surgical resection at a more conservative diameter of 5-5.5 cm depending on patient risk factor profile[9-12]. Interestingly, objective data supporting either an aggressive or conservative strategy remain sparse, reinforcing the necessity to establish studies focusing on the natural history of BAV aortopathy. Unfortunately, obtaining natural history data to define the true risks involved, particularly in the face of effective and definitive surgical therapies, is inherently difficult.

Since the 2000 era, specialized teams and clinics in the management of thoracic aortic disease have emerged. In effect, the management of risk factors as well as rigorous imaging surveillance may influence the aortic growth rate and incidence of acute adverse events. Through prospective data collected in our thoracic clinic, we have reported an annual growth rate of 0.42±0.76mm/yr for medically treated root/ascending aortic aneurysms in TAV patients, a much lower growth rate than those reported in historic studies on which recommendations are

based[10,12,13]. Consequently, we sought to better understand the growth rates of ascending aortic aneurysms in a BAV aortopathy population.

The present study specifically evaluates the growth rate, adverse events and late outcome of BAV aortopathy in comparison with TAV root/ascending aortic aneurysms.

MATERIAL AND METHODS:

At the Quebec Heart and Lung Institute (Institut Universitaire de Cardiologie et de Pneumologie de Québec IUCPQ) a dedicated Thoracic Aortic Clinic has been instituted in 2002. Concomitantly, a prospective databank has been established and approved by the IUCPQ research review board and scientific committees. Informed consent was obtained from all patients in the study.

Patient Inclusion Criteria and Follow-up:

We sought to identify a precise cohort of patients with a root/ascending aortic diameter between 40-50 mm in order to assess their natural history. Consequently, we identified patients followed at the IUCPQ since 2002 with these aortic diameter ranges. Patients required at least 2 chest computed tomographies (CT) at follow-up. Transthoracic echocardiography was performed and aortic valve morphology evaluated for the presence of a bicuspid valve. Patients with genetic syndromes or connective tissue disease were excluded. Other exclusion criteria included valvular morphology other than TAV or BAV, aneurysmal etiology other than atherosclerosis, medial cystic necrosis, or annular ectasia, or previous ascending aortic intervention or AVR.

Patients were followed annually at the Thoracic Aortic Clinic. Annual 24-hour blood pressure monitoring was performed and target blood pressure was <130/80mmHg. Kinesiology evaluations were performed to assess blood pressure on VO_2 max and during isometric exercises using standardized protocols. Furthermore, smoking cessation counselling was provided and serum lipid profile optimized.

Imaging Protocol:

Once the diagnosis of root/ascending TAA was established, thoracic CT follow-up was performed 1 year after and 12-24 months thereafter. CTs were either performed at the IUCPQ or

at a referral center. All images were sent to the aortic clinic and measurements were completed prospectively in a standardized fashion by 2 experienced surgeons (FD, ED). CT aortic measurements were performed on axial images with diameters assessed at the aortic sinuses, mid-ascending aorta (at the carina level), mid-arch (just distal to the innominate artery), at the aortic isthmus (distal to the left subclavian artery) and the mid-descending aorta (at level of carina). Measurements were obtained on contrast-enhanced CT images using the outer to outer diameter. In cases where the measurements were inconclusive on the axial cuts either owing to oblique cuts or measurements inferior to the previous CT, measures in the sagittal or coronal plans were analyzed and noted within the patient's chart to ensure comparable measures for future CT controls. The largest diameter of the root/ascending aorta was registered as maximal root/ascending aortic diameter.

End-points and Data Analysis:

Maximum aortic diameters of the root/ascending aorta were compared throughout the study period. Yearly aortic growth was defined as maximal root/ascending aortic diameter at the last CT – maximal root/ascending aortic diameter at the first CT divided by the timeframe between the first and the last CT. Surgical data on operative mortality, survival, and incidence of aortic valve or aortic intervention was collected and compared between subgroups. We also sought to further evaluate differences between patients who had aneurysmal progression - defined as growth >2 mm - and those who remained stable in our patient population throughout the study period. Institutional preference varied according to guidelines although operation was often-time suggested in low-risk patients at a root/ascending aortic diameter > 50mm especially in patients with BAV with hypertension and living at large distances from our center.

Statistical Analysis:

All continuous descriptive variables are reported as mean with standard deviations and median with IQR. Student's t-tests or Wilcoxon rank-sum tests were performed to compare groups. Nominal variables are reported as frequencies. Fisher's exact test was used to test if the samples come from the same distribution. Overall survival and freedom from event at follow-up was constructed using Kaplan-Meier estimates. The log-rank test was used for group comparisons. Patient's characteristics and comorbidities variables were investigated to identify prognostic factors that may be associated with survival. A Cox proportional hazard regression analysis was performed to model survival. The variables retained were age, COPD, peripheral vascular disease and hypertension. The Martingale residuals were used to examine the functional form of the continuous variable age and to conclude that no transformation was necessary. All these variables were checked for the adequacy of the proportional hazards assumption. The results were considered significant with p-values <0.05. Analyses were conducted using the statistical package SAS, version 9.4 (SAS Institute Inc., Cary, NC.)

RESULTS:

Among 1089 patients followed at the aortic clinic, 572 patients met the inclusion criteria: 104 with BAV and 468 with TAV. A total of 68 patients underwent surgical intervention for either valvular or aortic disease (BAV 32.7% vs TAV 7.3%, p<0.0001).

Patient characteristics are listed in Table 1. Mean follow up for patients with BAV was 6.9±3.4 (imaging: 4.3±2.6) years and TAV was 6.4±3.0 (imaging: 3.8±2.5) years. Patients with TAV were generally older (BAV 56.5±10.6 vs TAV 66.9±9.9 years; p<0.0001), more hypertensive (BAV 54.4% vs TAV 69.2%; p=0.01) and had higher rates of COPD (BAV 1.9% vs TAV 9.9%; p=0.01). Peripheral vascular disease trended higher in patients with TAV (BAV 2.9% vs TAV 8.6%; p=0.06). Maximal aortic root/ascending size was larger in patients with BAV (BAV 46.5±2.3 vs TAV 45.2±3.0 mm, p<0.0001). In our cohort, only 107 patients (18.7%) demonstrated aneurysmal progression >2 mm (BAV 19.2% vs TAV 18.6%; p=0.89; Figure 1).

Surgical data outcomes are illustrated in Table 2. In-hospital mortality was 0%, and overall mortality at follow-up was 10.3%. Adjusted survival curves, depicted in Figure 2, demonstrate no survival difference between BAV vs TAV at 5 (96.7% vs 96.6%) and 10 years (91.2% vs 90.8%) (p=0.94). We also evaluated survival data between patients who demonstrated aneurysmal progression >2 mm, with no difference in outcome (Figure 3, log rank p=0.23). Patients with BAV had more surgical intervention (BAV 32.7% vs TAV 7.3%, p<0.0001), largely driven by valvular disease in BAV (BAV 47.1% vs TAV 32.4%) versus aneurysmal growth in TAV (BAV 41.2% vs TAV 52.9%). Of those who underwent intervention, 97.1% were performed on an elective basis, with only 1 emergent procedure in the entire cohort for an acute aortic intramural hematoma after 3 years of follow-up. Freedom from surgery Kaplan-Meier curves are illustrated in Figure 4-5.

Patient demographics comparing patients with significant (>2 mm) vs stable aneurysmal

growth is illustrated in Table 3. The distribution of patients with BAV vs TAV was similar in both groups. Table 4 demonstrates similar surgical data. Patients who did progress >2 mm underwent more surgical intervention (25.2% vs 8.8%; p<0.0001), largely driven by aneurysmal progression (81.5% vs 24.4%; p<0.0001) compared to those who didn't progress, for which valvular intervention superseded (14.8% vs 56.1%; p<0.0001).

During the study period, root/ascending aortic growth was comparable among groups: BAV: 0.39±0.57 mm/yr vs. TAV: 0.43±0.80 mm/yr, p=0.64. Annual growth rate was comparable for patients with an initial root/ascending diameter of 40-45 mm: BAV: 0.48±0.86 mm vs. TAV: 0.44±0.92mm, p=0.85 and 45-50 mm: BAV: 0.37±0.49 mm vs. TAV: 0.43±0.71 mm, p=0.51. Only 23 patients (19.2%) with BAV aortopathy and 87 patients (18.6%) with a TAV aneurysm showed a root/ascending aortic diameter increase >2mm/year (p=0.89) while 2 (1.9%) patient in the BAV group and 25 (5.3%) in the TAV group increased >5mm during the entire follow-up period (p=0.20). Growth rates stratified by cumulative duration of follow-up are illustrated in Figure 6.

CONCLUSIONS:

Mainly owing to a lack of consensus and knowledge of the natural history of BAV aortopathy, decision-making regarding optimal aortic diameter thresholds for surgical intervention differs among institutions and countries. In a nationwide Canadian survey on management of BAV aortopathy among 100 cardiac surgeons, significant gaps in knowledge were identified with approximately a third of surgeons stating they would resect an undersized ascending aorta[14]. The economic burden of BAV has been evaluated to exceed 1 billion dollars in the USA, further stressing the importance to better define the natural history of the disease[15].

Annual growth rates for aneurysms of the ascending aorta have been reported between 0.2-2.8 mm[15-17]. While data on aortic growth are consistently higher with Marfan's syndrome, reports assessing growth rate in BAV aortopathy are conflicting. Detaint and colleagues reported a maximal root/ascending aortic dilatation of 0.42±0.6 mm/yr in BAV patients with aneurysms >40mm - dilatation comparable to Marfan patients (0.49±0.5 mm/yr) and significantly higher than patients with degenerative TAV aneurysms (0.20±0.3 mm/yr)[18]. On the other hand, La Canna and colleagues showed similar root/ascending aorta growth rate in BAV (0.81±1.1 mm/yr) and TAV (0.75±1.1 mm/yr) patients with aneurysms. The present study supports similar annual growth rate of the root/ascending among patients with BAV or TAV aneurysms. While the arch growth showed similar results between BAV and TAV patients, growth rates trended to be lower in the descending thoracic aorta in BAV patients. This finding is consistent with the distinctive pattern of BAV aortopathy limited to the root/ascending aorta with or without arch involvement and sparing of the distal thoracic aortic segments[19].

The risk of aortic dissection with BAV is approximately 8 times higher than in the general population[22]. However data regarding the absolute incidence of aortic dissection with BAV aortopathy remains limited. Prophylactic surgery renders it difficult to assess the risk of aortic

dissection in BAV aortopathy. In one study, 27 patients with BAV aortopathy were followed for 40 months without a single acute event being documented[23]. In another study, at 8.1 years of follow-up only 2 patients (0.1%) of a cohort of 1890 patients presented an acute aortic dissection[22]. A recent trial compared the risk of dissection in non-syndromic, Marfans, and BAV aortopathy, with rates at 10 years of 3.6±1.4%, 7.9±2.2% and 0%, respectively[24]. No acute adverse aortic-related event was observed in the present study in the BAV group, supporting the low risk of acute dissection in non-surgical medically treated BAV aortopathy.

Patients with BAV show excellent long-term survival, reported up to 90% at 20 years[25]. We report excellent long-term survival in our BAV and TAV cohort, despite a higher incidence of surgical resection with BAV aortopathy patients. A larger proportion of BAV patients were operated on due to both valvular disease and aortic size. With the fluctuating recommendations during the last two decades for operative indication for ascending aortic aneurysms in BAV patients, our trend was to consider operative indication at diameters >50mm especially in presence of concomitant high blood pressure or if patients live far from our referral center. Although operative outcome was excellent, the low rate of acute events in this study supports potentially a more *conservative* approach to aortic intervention, particularly in bicuspid aortic valves. Further data assessing outcome of patients with aneurysms between 50-55mm will confirm current recommendations to intervene on root / ascending aortic aneurysms at 55 mm either in BAV or TAV patients.

This study reinforces contemporary imaging recommendations in this specific patient population of medically-managed cohort. Currently, yearly imaging is suggested in non-surgical, medically treated ascending aortic aneurysms, but can be performed every 2-3 years in patients with confirmed stability of aneurysms measuring 40-49 mm[4,11]. With the very low growth rate and acute event reported in this study, we recommend imaging every 18-24 months in

medically treated stable ascending aortic aneurysm patients. Furthermore, transthoracic echocardiography may be useful for follow-up of patients with concomitant aortic valve disease. The efficacy of a diligent and dedicated aortic clinic cannot be emphasized enough. Blood pressure evaluation using daily weights (isometric testing) and at maximal VO_2 may identify high blood pressure responders and require intensification of the medical treatment and limitation of activity level specific for each patient. Further data may elucidate markers of poor prognosis and consequently earlier surgical intervention in BAV aortopathy.

Study limitations:

One of the limitations is that this was a retrospective analysis of a prospectively collected aortic clinic database. Our patient population is uniquely tied to our large-volume sole regional center in Quebec with exceptional follow up. However, due to a large volume of our patient population, our follow-up was limited as we referred a proportion of patients with no evidence of aneurysmal growth to family physicians. However, any patients with concerning aneurysmal growth were referred back to our center. Provincial mortality rates are also available for all patients in the provincial EMR, with only 3.8% of patients with unidentified causes of mortality. However, only 2 of these long-term deaths were potentially attributed to acute aortic complications.

One of the limitations of the study was that measurements for aortic diameter were performed on axial cuts . Asymmetric dilatation may confound measures although care was taken to use sagittal and coronal cuts (with specific notice in the aortic databank) in such circumstances by two surgeons allowing reproducibility in imaging data acquisition. Currently, double oblique plane measurements are much less prone to error compared to axial diameters. Given that our database started as far back as 2002, axial measurements were the standard of care during that time period and mirror the practice methodology still used multiple institutions. Future studies

incorporating double oblique plane measurements may be required to confirm findings of the present study.

Furthermore, dilatation was not indexed to body surface area, which may be relevant in small body surface area patients. Finally, the BAV aortopathy group compromises a heterogeneous group of patients without risk stratification such as pattern of BAV, aortic wall thickness or asymmetric vs symmetric dilatation. In addition, the higher operative rate in the BAV group may bias the natural history of the aortic growth.

Conclusions:

The present study suggests a slow aortic growth rate in non-surgical, medically treated BAV aortopathy patients comparable to aneurysms in TAV patients. The rate of aortic-related adverse events is very low at mid-term. Owing to this slow aortic growth pattern, we propose to modulate the imaging surveillance and perform a CT/MRI evaluation one year following the diagnosis, and subsequently at an 18-24 month interval in patients with stable disease and continue on a yearly basis in patients showing an annual growth rate >2 mm. Use of transthoracic echocardiography may further allow an extension period between CT/MRI examination in patients with stable disease. Furthermore, considering the low rate of acute event, our study does not support replacing the root/ascending aorta in patients at a threshold of 50mm. Further data among the patients with aneurysms in the range of 50-55mm is required to support current recommendations. In addition, long-term studies are required to confirm the fate of the BAV aorta and the impact of adverse event markers that could justify an intervention at an earlier stage.

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Table 1: Patient Demographics for Bicuspid vs Tricuspid Patients

	N (%) All patients N=572	N (%) BAV N=104	N (%) TAV N=468	p
Age, years, means±std	65.0±10.8	56.5±10.6	66.9±9.9	<0.0001
Median(IQR)	66 (58-73)	56 (51.5-63.5)	68 (61-74)	
Sex (F)	149 (26.1)	25 (24.0)	124 (26.5)	0.71
BMI kg/m^2, means±std	28.1±5.1	27.9±5.1	28.2±5.1	0.66
Median(IQR)	27.5 (24.8-30.8)	26.8 (24.6-31)	27.7 (24.6-31)	
Hypertension	380 (66.6)	56 (54.4)	324 (69.2)	0.01
Diabetes	55 (9.7)	14 (13.6)	41 (8.8)	0.14
Chronic renal failure	23 (4.1)	1 (1.0)	22 (4.8)	0.10
COPD	48 (8.5)	2 (1.9)	46 (9.9)	0.01
History or Active smoker	213 (39.2)	57 (58.2%)	273 (61.4%)	0.57
Hyperlipidemia	266 (47.3)	44 (43.6)	222 (48.1)	0.44
PVD	43 (7.5)	3 (2.9)	40 (8.6)	0.06
CAD	95 (16.7)	12 (11.8)	86 (17.8)	0.19
Maximal root/ascending size (mm), means±std	45.5±2.9	46.5±2.3	45.2±3.0	<0.0001
Median(IQR)	46 (43-48)	47 (45-48)	46 (43-48)	
40-44mm	202 (35.3)	19 (18.3)	183 (39.1)	
45-50mm	370 (62.8)	85 (81.7)	285 (60.9)	<0.0001
Progression >2mm	107 (18.7)	23 (19.2)	87 (18.6)	0.89

BMI: Body mass index
COPD: Chronic obstructive pulmonary disease
CAD: Coronary artery disease
PVD: Peripheral vascular disease

Table 2: Operative Rates and Outcomes

	N (%) All patients N=572	N (%) BAV N=104	N (%) TAV N=468	p
Aortic replacement and/or AVR	68 (11.9)	34 (32.7)	34 (7.3)	<0.0001
Reason for operation				0.46
Valve disease progression	27/68 (39.7)	16/34 (47.1)	11/34 (32.4)	
Aneurysm progression (≥50mm)	32/68 (47.1)	14/34 (41.2)	18/34 (52.9)	
Asc aorta Diameter at surgery, mm means±std	51.9±2.0	51.1±1.1	52.5±2.3	0.04
Median(IQR)	51.5 (50-53)	51 (50-52)	52 (50-54)	
Other ∞	9/68 (13.2)	4/34 (11.8)	5/34 (14.7)	
Asc aorta Diameter at surgery, mm means±std	45.3±3.2	47.3±1.0	43.8±3.6	0.11
Median(IQR)	47 (45-47)	47.5 (46.5-48)	45 (40-47)	
Aortic valve procedure	61 (10.7)	33 (31.7)	28 (6.0)	<0.0001
Root replacement	23/61 (37.7)	9/33 (27.3)	14/28 (50.0)	0.11
Aortic valve replacement	43 (7.5)	28 (26.9)	15 (3.2)	<0.0001
Mechanical valve	4/43 (9.3)	4/28 (14.3)	0/15 (0)	0.12
Biologic valve	39/43 (90.7)	24/28 (85.7)	15/15 (100)	
Aortic valve plasty	18 (3.2)	5 (4.8)	13 (2.8)	0.35
Arch procedure	20 (3.5)	8 (7.7)	12 (2.6)	0.02
Complete arch	5/20 (3.5)	0/8 (0)	5/12 (41.7)	0.05
Descending aortic procedure	18 (3.1%)	1 (0.96)	17 (3.6)	0.22
Elective procedure	66/68 (97.1)	33/34 (97.1)	33/34 (97.1)	0.37
Urgent procedure	1/68 (1.4)	1/34 (2.9)	0	
Emergent procedure	1/68 (1.4)	0/34	1/34 (2.9)	
Aortic dissection	0/68	0/34	0/34	---
Hospital mortality	0	0	0	---

Table 3: Patient Demographics for Progression vs Minimal Progression

	N (%) All patients N=572	N (%) Progression >2 mm N=107	N (%) No progression or ≤2 mm N=465	p
Age, years, means±std	65.0±10.8	64.1±12.0	65.2±10.5	0.35
Median(IQR)	66 (58-73)	66 (54-73)	66 (58-73)	
Sex (F)	149 (26.1)	31 (29.0)	118 (25.4)	0.46
BMI kg/m^2, means±std	28.1±5.1	27.2±4.4	28.3±5.2	0.04
Median(IQR)	27.5 (24.8-30.8)	26.6 (24.4-30.0)	27.8 (25.1-30.9)	
Hypertension	380 (66.6)	64 (59.8)	316 (68.1)	0.11
Diabetes	55 (9.7)	9 (8.4)	46 (9.9)	0.72
Chronic renal failure	23 (4.1)	9 (8.5)	14 (3.1)	0.02
COPD	48 (8.5)	8 (7.6)	40 (8.7)	0.85
History or Active smoker	213 (39.2)	63 (63.6)	267 (60.1)	0.57
Hyperlipidemia	266 (47.3)	42 (41.2)	237 (51.4)	0.19
PVD	43 (7.5)	8 (7.5)	35 (7.6)	1.0
CAD	95 (16.7)	18 (17.0)	77 (16.7)	1.0
Maximal root/ascending size (mm), means±std	45.5±2.9	45.1±3.0	45.5±2.9	0.14
Median(IQR)	46 (43-48)	45 (42-48)	46 (43-48)	
40-44mm	202 (35.3)	39 (36.5)	163 (35.0)	0.82
45-50mm	370 (62.8)	68 (63.5)	302 (65.0)	
Bicuspid valve	104 (18.2)	20 (18.7)	84 (18.1)	0.89
Tricuspid valve	468 (81.8)	87 (81.3)	381 (81.9)	0.89
Aortic aneurysm etiology				
Atherosclerosis	287 (50.2)	53 (49.5)	234 (50.3)	
Bicuspid aortic valve	104 (18.2)	20 (18.7)	84 (18.1)	0.98
Annulo ectasia	181 (31.6)	34 (31.8)	147 (31.6)	

Table 4: Operative Data and Outcomes

	N(%) All patients N=572	N (%) Progression >2 mm N=107	N (%) No progression or ≤2 mm N=465	p
Aortic replacement and/or AVR	68 (11.9)	27 (25.2)	41 (8.8)	<0.0001
Reason for operation				
Valve disease progression	27/68 (39.7)	4/27 (14.8)	23/41 (56.1)	<0.0001
Aneurysm progression (≥50mm)	32/68 (47.1)	22/27 (81.5)	10/41 (24.4)	
Asc aorta Diameter at surgery, mm means±std	51.9±2.0	52.4±2.1	50.7±0.9	0.02
Median(IQR)	51.5 (50-53)	52 (51-54)	50 (50-52)	
Other ∞	9/68 (13.2)	1/27 (3.7)	8/41 (19.5)	<0.0001
Asc aorta Diameter at surgery, mm means±std	45.3±3.2	47.0	45.1±3.3	0.61
Median(IQR)	47 (45-47)		46.5 (42.5-47.5)	
Arch procedure	20 (3.5)	9 (8.4)	11 (2.4)	0.01
Descending aortic procedure	18 (3.1)	7 (6.5)	11 (2.4)	0.06
Elective procedure	66/68 (97.1)	27/27 (100)	39/41 (95.1)	0.51
Urgent procedure	1/68 (1.4)	0/27	1/41 (2.4)	
Emergent procedure	1/68 (1.4)	0	1/41 (2.4)	
Aortic dissection	0/68	0/27	0/41	---
Hospital mortality	0	0	0	---

FIGURE LEGENDS:

Figure 1. Freedom from Progression > 2 mm with BAV vs TAV

Figure 2. Kaplan-Meier survival curve with TAV vs BAV

Figure 3. Kaplan-Meier survival curve for patients with and without aneurysmal progression

Figure 4. Freedom from Surgery Curve for patients with and without aneurysmal progression

Figure 5. Freedom from Surgery Curve for patients with BAV vs TAV

Figure 6. Cumulative aneurysm growth curves for BAV vs TAV.