Clinical Outcomes of Adults With Bicuspid Aortic Valve: A European Perspective

Charles Cheng, Yohann Bohbot, Hector Michelena, Dan Rusinaru, Floriane Fay, Frederic Elmkies, Maurice Enriquez Sarano, Christophe Tribouilloy

Version of Record: https://www.sciencedirect.com/science/article/pii/S0025619620308442
Manuscript_9728956b3e3f87ae61a8b451d10f56ce

Clinical Outcomes of Adults With Bicuspid Aortic Valve: A European Perspective

Authors:

Charles Cheng, MD[1*], Yohann Bohbot, MD[1,2*], Hector I. Michelena, MD[3], Dan Rusinaru, MD, PhD[1,2], Floriane Fay, MD[1], Frederic Elmkies, MD[1], Maurice Enriquez Sarano, MD[3] and Christophe Tribouilloy, MD, PhD[1,2]

Affiliations:

1 Department of Cardiology, Amiens University Hospital, Amiens, France

2 EA 7517 MP3CV Université de Picardie Jules Verne, Amiens, France

3 Division of Cardiology, Mayo Clinic Rochester, MN, USA

*CC and YB contributed equally to this study and are joint first authors

Brief title: Outcome of bicuspid aortic valve

Funding sources: None
Financial support and conflict of interest disclosure: None

Reprints and correspondence:

Professor Christophe Tribouilloy, MD, PhD

EA 7517 MP3CV Université de Picardie Jules Verne, Amiens, France and Amiens University Hospital, France

Department of Cardiology, Avenue René Laënnec, 80054 Amiens Cedex 1, France

Phone: 33 3-22-45-58-83; Fax: 33 3-22-45-56-58;

E-mail: tribouilloy.christophe@chu-amiens.fr

Word count: 2982/3000. Abstract 236/250

ABSTRACT

Objective: To describe the clinical history of patients with a wide age range diagnosed with bicuspid aortic valve (BAV) and no surgical indication and to evaluate the long-term outcome of BAV patients referred for elective surgery.

Patients and methods: Between 2005 and 2017, 350 consecutive patients with no surgical indication (surveillance group, mean age 53±16, 71% men) and 191 with a surgical indication (surgical group, mean age 59±13, 71% men) were prospectively included. Median follow-up was 80[32-115] months.

Results: In the surveillance group, the 5-year and 10-year survival rates were 93±1% and 89±2%, respectively, with a relative survival of BAV patients compared to an age-and-sex-matched control population of 98.7%. During follow-up, the cumulative 10-year incidence of aortic valve/aorta surgery was high, of 35±4%, the incidence of native valve IE of 0.2% per patient-year and no cases of aortic dissection were observed. In the surgical group, the 5-year and 10-year survival rates were 97±1% and 89±3%, respectively, with a relative survival of 99.4% compared to the general population. The incidence of IE was 0.4% per patient-year and no cases of aortic dissection were observed.

Conclusions: This regional cohort, shows that the 10-year survival rates of BAV patients with a wide age range but mostly middle-aged adults, were similar to those of the general population with a very low rate of complications. Adherence to prophylactic surgical indications and younger age might have contributed to this lack of difference.

KEYWORDS: bicuspid aortic valve, outcome, survival, surgery, aorta, .

ABBREVIATIONS

AA: ascending aorta

AD: aortic dissection

AR: aortic regurgitation

AS: aortic stenosis

AVA: aortic valve area

BAV: bicuspid aortic valve

IE: infective endocarditis

LV : left ventricular

LVEF : left ventricular ejection fraction

VS: Valsalva sinuses

INTRODUCTION

Bicuspid aortic valve (BAV) is the most common congenital cardiac abnormality(1) that has been touted to cause a cardiovascular morbidity burden higher than all other congenital heart diseases(2). Nevertheless, the BAV condition remains poorly understood from several perspectives. On one hand, the high morbidity burden(2), the progression of aortic dilatation similar to Marfan's disease(3) and calls for indicating aortic surgery at an early stage of aortic dilatation based on a high risk of aortic dissection (AD)(4) have suggested a high potential for ominous prognosis. Conversely, a US and a Canadian longitudinal series, suggested(5,6) that BAV could be associated with normal life expectancy and very low rate of AD at the cost of high rates of aortic valve/ aorta surgery(7-10). However, these studies do not resolve fully the concern for the potential complications due to BAV.. Indeed, the 2 North American series(5,6) enrolled overwhelmingly very young carriers of BAV and the good outcome may have more to do with the youth of the patients than the BAV itself. The Olmsted County study(6) included also patients that were quite young at diagnosis and was conducted in the

community where care is provided by the Mayo Clinic, a high-volume center of excellence. Therefore, it is unclear whether it is the care provided or the natural history of BAV that explain the good outcomes observed, or both. It is important to know whether such results can be generalized and if the good long-term clinical outcome of BAV can be achieved in the circumstances of a regional medical center. Indeed, to our knowledge, no data are available regarding the natural history and outcome of European BAV patients with a broad age range, as the 2 largest studies were conducted on young adults in North America(5,6).

Therefore, our objectives were to gather a large cohort of adults with BAV, dwelling in the Somme French department to (i)describe the clinical history of adults diagnosed with BAV under those auspices and to (ii)evaluate the long-term outcome of BAV patients referred for elective surgery. We aimed at determining the rates of cardiovascular events, and assessing the long-term survival relative to that of the general population receiving a standard medical care.

METHODS

Study population

Between January 2005 and December 2017, consecutive patients≥18 years of age diagnosed with BAV at our echocardiographic laboratory were prospectively identified and included in an electronic database. The present analysis was based on 541 consecutive patients with BAV:350 without an indication for surgery at inclusion (surveillance group) and 191 with an indication for aortic valve and/or ascending aorta surgery, operated within 6 months following inclusion (surgical group). The study was approved by an independent ethics committee and was conducted in accordance with institutional policies, national legal requirements, and the revised Declaration of Helsinki.

Echocardiography

All patients underwent a comprehensive Doppler-echocardiographic assessment using

commercially available ultrasound systems. BAV was diagnosed in the short axis view based on Sievers and Schmidtke classification and was confirmed by another imaging technique when there was a doubt about the diagnosis. Aortic flow was systematically recorded using continuous wave Doppler on several views. Aortic valve area(AVA) was calculated using the continuity equation. AS was defined by AVA<2 cm² and aortic regurgitation(AR) was classified as mild, moderate or severe using an integrated approach(11). AR was considered significant when it was greater than mild. Measurements of aortic Valsalva sinuses(VS) and proximal ascending aorta(AA) dimensions were performed at end-diastole in a strictly perpendicular plane to that of the long axis of the aorta using the leading-edge method. Dilatation of VS and/or AA was defined by dimensions ≥40 mm(12).

Follow-up

Median [interquartile range] follow-up was 80[32-115] months. Most patients were followed annually by clinical consultations and echocardiography. Follow-up was closer for patients approaching surgical thresholds (twice a year) but less frequent for those with nondilated aorta and normal/ minimally dysfunctional valves (every 2 to 3 years). Some patients were followed in public hospitals or private practices by referring cardiologists working in collaboration with our center. Information on follow-up was obtained yearly over the same period for the entire cohort. Follow-up was complete up until death or the end of the study (2017) for 97% of patients. Clinical decisions regarding surveillance and referral for surgery were taken by the heart team with the approval of the patient's cardiologist in accordance with practice guidelines in place at the time of the inclusion(8-10). Causes of deaths were ascertained by hospital records, death certificates and autopsy records, or by contacting the patient's physician. Patients of the surveillance group operated-on during follow-up remained in this group. Survival encompassed all modalities of surveillance and surgical management.

Statistical analysis

Data were analyzed using SPSS 25.0 (SPSS Inc. Chicago, IL). Continuous variables are expressed as mean±standard deviation or median [interquartile range], and categorical variables are expressed as numbers and percentages. Patients were retrospectively divided into 3 groups according to valve function (normal or minimally dysfunctional aortic valve, AS and AR). The relationship between baseline continuous variables and the various groups was explored using one-way ANOVA tests. Pearson's chi-square statistic or Fisher's exact test was used to examine the association between the various groups and baseline categorical variables. The significance between the reference group and the other groups was examined when a significant difference across categories was observed. Individual differences were compared with Mann-Whitney U tests and Tukey tests for normally distributed data. Event rates±standard errors were estimated using the Kaplan-Meier method and compared by two-sided log-rank tests. Each patient with BAV was matched for the average survival (per year) of all patients of the same age and same gender from our region (Somme, department of 555,551 inhabitants, north of France). Control data were obtained from Somme life tables established on the basis of the 1999 population census carried out by the French Institute of National Statistics and represent the survival of the entire Somme general population(13). Survival rates of BAV patients were compared with the expected survival of persons of the same age and gender in the Somme department. Relative survival was computed as the ratio of observed-to-expected survival (observed number of deaths in the BAV population/expected number of deaths in the general population). Factors associated with surgery performance were identified by a multivariate logistic regression model including all significant variables in univariate analysis with $p < 0.1$. The limit of statistical significance was $p < .05$ and all tests were two-tailed.

RESULTS

Surveillance group

BAV was mostly discovered incidentally during a systematic echocardiogram (n=168;48%). Baseline clinical characteristics of the 350 patients without a surgical indication at inclusion (71.1% of men, mean age 53±16) are displayed in **Tables 1 and 2**. Most patients were in NYHA class I or II (95.1%), 164(46.8%) had hypertension, 48(13.7%) were diabetics and CAD was diagnosed in 31(8.8%) patients. Patients with AS (n=142,40.5%) were older (*P*<.001), more often diabetics with more comorbidity (both *P*<.05) and more often had a history of atrial fibrillation (*P*<.001) than patients with normal or minimally dysfunctional aortic valve (n=128,36.6%; reference group) (**Table 2**). Eighty patients (22.9%) had moderate-to-severe AR. Patients with moderate-to-severe AR had greater aortic (LV outflow tract [*P*<.001], VS and AA [both *P*<.05]) and LV diameters (*P*<.001) and larger left atrium area (*P*<.05) compared to the reference group (**Table 2**). One hundred and sixty seven(48%) had an enlarged aorta

During follow-up, 34 deaths (9.7%) occurred, 10 of which (29%) were cardiovascular-related. The 5-year and 10-year survival rates were 93±1% and 89±2%, respectively. The 10-year relative survival of BAV patients compared to the age-and-sex-matched population was 98.7% (**Figure 1A**). During follow-up, 9 patients (2.6%) were diagnosed with IE: 5 with native aortic valve IE and 4 with prosthetic IE (incidence of 0.4% per patient-year [0.2% per patient-year for native valve IE]): 5 patients required urgent surgery and 4 patients were treated medically. No AD occurred during follow-up. The 5-year and 10-year event-free survivals (cardiovascular death, IE or AD) were 96±1% and 91±2%, respectively.

During follow-up, 102 patients(29%) underwent aortic valve and/or ascending aorta surgery (**Table 3**)(98% in our center) and the diagnosis of BAV was confirmed by the surgeon and/or the pathologist for all patients. On Kaplan-Meier analysis, the 2-year, 6-year and 10-year cumulative surgery rates were 3±1%, 11±2%, and 35±4%, respectively(**Figure 2**). In multivariate logistic regression analysis, NYHA stage (Adjusted OR:3.99[2.04-7.82] per

class;*P*<.001), Doppler peak aortic velocity (Adjusted OR:1.95[1.51-2.52] per m/s;*P*<.001) and ascending aorta diameter(Adjusted OR:1.06[1.01-1.12] per mm;*P*=.04) were independently associated with surgery performance(**Supplemental table 1).**

Surgical group

Baseline characteristics of the surgical group (191 patients operated within 6 months following inclusion) are displayed in **Table 1 and supplemental Table 2**. Indications for surgery and surgical procedures (98.5% performed in our center) are reported in **Table 3**. The diagnosis of BAV was confirmed for all patients during surgery. Patients with severe AS were older(*P*<.001), had more comorbidity(*P*<.05) and smaller aortic dimensions(*P*<.001) compared to patients with normal or minimally dysfunctional aortic valve (reference group) (**Supplemental table 2**). Patients with severe AR were younger (*P*<.001), had greater LV diameters(*P*<.001) and lower LVEF(*P*<.001) compared to the reference group (**Supplemental table 2**). One hundred and fourteen patients(60%) had an enlarged aorta.

During follow-up, 12 deaths(6.3%) occurred, 5 of which(2.6%) were cardiovascular-related. Perioperative mortality was 0.5%(n=1). The 5-year and 10-year survival rates were 97±1% and 89±3%, respectively. The 10-year relative survival of BAV patients compared to the age- and sex-matched population was 99.4%(**Figure 1B**). The 5-year and 10-year event-free survivals (cardiovascular death, IE, AD and reoperation) were 98±1% and 87±4%, respectively. During follow-up, 5 patients were diagnosed with prosthetic IE(incidence of 0.4% per patient-year) and no AD or valve thrombosis occurred. Only 5 patients were operated during follow-up: 2 for bioprosthetic degeneration(at 7 and 10 years respectively, estimated rate of 5±3% at 15 years) and 3 for IE.

DISCUSSION

To the best of our knowledge, this long-term follow-up study of 541 consecutive patients is the first large-scale European series providing important information about the clinical history

and outcomes of BAV in adults of a wide range age but mostly middle-aged. The present cohort gathered in a regional medical center in Europe, shows that under surveillance, 10-year mortality is low, not different from expected, provided that the guidelines for indication of surgery are followed. Complication rates are relatively low and are generally manageable. Patients often require cardiac surgery during follow-up but outcomes after surgery are generally excellent with in our study, post-operative survival at 10-years comparable to that of the general population. In adults carriers of BAV, the 10-years outcomes observed in Europe are very coherent with observed in North-America, without variance related to the medical care system, the type those of institution managing the patients or the age at diagnosis, and emphasizing a generally good survival at the cost of a high rate of cardiac or prophylactic aortic surgery warranting careful monitoring of the progression of the aortic valve and ascending aortic alterations.

Natural history of BAV patients

Two larges cohorts from North-America have focused on the natural history of BAV in young adults with no surgical indication at baseline(5,6), providing crucial information but leaving important doubts related to either youth of the population or the nature of the care received by these patients. Indeed, a Canadian cohort of 642 asymptomatic young adults (mean age 35 years, mean follow-up 9 years) with BAV and a spectrum of valve function, showed a 10-year survival of 96±1%(3). The population-based cohort of Olmsted County, involved asymptomatic young adults with BAV(mean age 32, mean follow-up 15 years) and no significant valve dysfunction at baseline, also demonstrated an excellent survival of 90±3%(6). However, due to the specific circumstances of each cohort, it is not possible to ascertain whether these good outcomes truly represent the “natural” history of adults with BAV. In our population diagnosed at an older age(mean age 53±16 years), the 10-year survival was comparable to that of the general French population. Hence our series from a

regional center in Europe enrolling patients diagnosed mostly in their middle-age demonstrates that indeed BAV "good" outcomes can now be attributed without a doubt to the BAV itself and not to the patients' age, or recruitment in high-ranking referral centers, so that we can affirm that such results are truly generalizable to the adult population.

The main event observed during follow-up in BAV patients was aortic valve and/or ascending aorta surgery. In the study by Michelena et al, 29% of patients underwent surgery (mean follow-up:15 years)(6) and 22% in the study by Tzemos et al (mean follow-up:9 years)(5). The 10-year surgery rate was higher(35±4%) in our study, probably because of the more advanced age of our population. Moreover, the risk of AVR after 25 years could reach more than 50%(7).

The most dreaded complication of BAV is AD, which is associated with high mortality. The incidence of AD has been estimated for BAV patients to be eightfold higher than in the general population, but still remains exceedingly low from 0.015 to 0.03% per year, if the guidelines in terms of follow-up and indications for prophylactic aortic surgery are followed(7,14). In the Toronto series(5), during 9 years of follow-up, only 2 AD out of 642 patients occurred and, in the Olmsted County study, no AD occurred during follow-up(6). Similarly, in our study, following the guidelines for prophylactic aortic surgery(50mm before 2012 and 55mm since) no case of AD was observed during follow-up.

IE is a severe complication of BAV and warrants prompt diagnosis and treatment. Furthermore, BAV patients with IE incurs higher severity of complications as compared to tricuspid aortic valves with high risk of abscess formation and often require early surgery(15). Older series have estimated the prevalence of IE to be between 10% and 30% in the presence of BAV(2). However, those studies presented numerous biases and more recent estimates of the incidence of IE are lower, at about 0.14% per patient-year(0.10% per patient-year for native valve IE)(16). Accordingly, in our study, the IE incidence was 0.4% per patient-

year(0.2% per patient-year for native valve IE).

Prognosis of BAV patients after surgery

The most common complication of BAV in adults is valve dysfunction requiring surgery, and the development of severe AS is the main indication for AVR(17), while AR is observed in only 10% to 15% of cases(17,18). Accordingly, in our surgical group, the indications for aortic valve surgery were severe AS in 65.5% of cases and severe AR in 13.5% of cases.

McKellar et al(19) and Sievers et al(20) reported that after AVR, the 5 and 10-years survival of patients with BAV was not different from the general population. Similarly, in our study, the 10-year survival of the surgical group was good (89±3%) and comparable to that of the general population(relative survival of 99.4%). Only 5 patients were reoperated for the aortic valve during follow-up.

BAV patients have larger aortic dimensions than adults with tricuspid aortic valves(1,21,22) with a risk of aortic aneurysm 80-fold higher than in the general population(14). In our study, about 40% of patients of the surgical group underwent ascending aorta surgery and only 6% of them had had an associated replacement of the aortic arch. McKellar et al(19) reported a 15-year freedom from AD, aortic enlargement, or replacement rate of 93% in patients with normal aortic dimensions at the time of AVR, but of only 85% in patients with aortic enlargement. In a population of 201 BAV patients with an aorta<5cm undergoing isolated AVR, 10 years after surgery, 22 patients(11%) had long-term complications related to the ascending aorta(23). Based on these data, guidelines, when aortic valve surgery is scheduled for severe AS and/or severe AR, consider associated prophylactic ascending aorta surgery in patients with maximum aortic diameter>45mm(8-10,24). In our study, when complying with the guidelines for prophylactic aortic surgery(8-10), no AD occurred and no patient required reoperation for the aorta during follow-up despite few preventive aortic arch replacement, in accordance with the study by Greason et al(25).

According to current guidelines(26,27), BAV Patients can be reviewed on a yearly basis and echocardiography performed every 2 years in case of mild to moderate AR and every year if asymptomatic severe AR without LV dysfunction. If the ascending aorta is dilated(>40mm) a computed tomography or magnetic resonance imaging is recommended at baseline, which should be repeated for increases>3 mm or when the patient is close to surgical thresholds. In other cases, aortic dimensions can be monitored by annual echocardiography, especially if exceeding 45 mm. In case of nondilated aorta and normal/minimally dysfunctional valve a longer interval between imaging studies seems appropriate(24,26,27).

Limitations

Significant improvements were made to Doppler echocardiographic techniques during the study period. However, we believe that the quality of imaging throughout this period was sufficient to diagnose BAV. When cusp numbers were not unequivocally determined by echocardiography, we confirmed the diagnosis by another imaging technique or the patients concerned were excluded. These results can only be interpreted at 10 years and some cases of AD could be observed with longer follow-up and a larger number of patients(28). Furthermore, it has been shown that BAV patients who present at later points in their clinical history when they are older (time of referral to a tertiary care facility and time of surgery), have higher mortality likely related to the accumulation of morbidity(28). Similar to the study of Tzemos et al(5), this was not a community-based study. However, our center is a tertiary center but also a regional center which takes care of the Somme region. We report for the first time, the follow-up of a large European cohort showing overall good survival despite being tertiary-referral-based.

CONCLUSION

In adults carriers of BAV, over the western world and diagnosed at any age, the 10-years outcomes observed in Europe are very coherent with observed in North-America, without

variance related to the medical care system, the type of institution managing the patients or the age at diagnosis, and emphasizing a generally good survival at the cost of a high rate of cardiac or prophylactic aortic surgery warranting careful monitoring of the progression of the aortic valve and ascending aortic alterations.

Acknowledgments: None

REFERENCES

1. Siu SC, Silversides CK. Bicuspid aortic valve disease. *J Am Coll Cardiol* 2010;55(25):2789-800.
2. Ward C. Clinical significance of the bicuspid aortic valve. *Heart* 2000;83(1):81-5.
3. Detaint D, Michelena HI, Nkomo VT, Vahanian A, Jondeau G, Sarano ME. Aortic dilatation patterns and rates in adults with bicuspid aortic valves: a comparative study with Marfan syndrome and degenerative aortopathy. *Heart* 2014;100(2):126-34.
4. 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(3):892-3.
5. Tzemos N, Therrien J, Yip J, et al. Outcomes in adults with bicuspid aortic valves. *JAMA* 2008;300(11):1317-25.
6. Michelena HI, Desjardins VA, Avierinos JF, et al. Natural history of asymptomatic patients with normally functioning or minimally dysfunctional bicuspid aortic valve in the community. *Circulation* 2008;117(21):2776-84.
7. Michelena HI, Khanna AD, Mahoney D, et al. Incidence of aortic complications in patients with bicuspid aortic valves. JAMA 2011;306(10):1104–1112.
8. Iung B, Gohlke-Bärwolf C, Tornos P et al. Recommendations on the management of the asymptomatic patient with valvular heart disease. *Eur Heart J*. 2002;23(16):1253-66.
9. Vahanian A, Baumgartner H, Bax J, et al. Guidelines on the management of valvular heart disease. The Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. *Eur Heart J* 2007;28(2):230-68.
10. Vahanian A, Alfieri O, Andreotti F, et al. Guidelines on the management of

valvular heart disease (version 2012) The Joint Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). *Eur Heart J* 2012;33(19):2451-96.

11. Lancellotti P, Tribouilloy C, Hagendorff A, et al. Recommendations for the echocardiographic assessment of native valvular regurgitation: an executive summary from the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2013;14(7):611-44.
12. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2015;16(3):233-71.
13. Tribouilloy C, Rusinaru D, Mahjoub H, et al. Prognosis of heart failure with preserved ejection fraction: a 5 year prospective population-based study. *Eur Heart J* 2008;29(3):339-47
14. Michelena HI, Prakash SK, Della Corte A, et al. Bicuspid aortic valve: identifying knowledge gaps and rising to the challenge from the International Bicuspid Aortic Valve Consortium (BAVCon). *Circulation* 2014;129(25):2691-2704
15. Tribouilloy C, Rusinaru D, Sorel C, et al. Clinical characteristics and outcome of infective endocarditis in adults with bicuspid aortic valves: a multicenter observational study. *Hear*t 2010;96(21):1723-9.
16. Michelena HI, Katan O, Suri RM, Baddour LM, Enriquez-Sarano M. Incidence of Infective Endocarditis in Patients With Bicuspid Aortic Valves in the Community. *Mayo Clin Proc.* 2016;91(1):122-3.
17. Borger MA, Fedak PWM, Stephens EH, et al. The American Association for

Thoracic Surgery consensus guidelines on bicuspid aortic valve-related aortopathy. *J Thorac Cardiovasc Surg* 2018;156(2):e41-74

18. Sabet HY, Edwards WD, Tazelaar HD, Daly RC. Congenitally bicuspid aortic valves: a surgical pathology study of 542 cases (1991 through 1996) and a literature review of 2,715 additional cases. *Mayo Clin Proc* 1999;74(1):14-26.

19. McKellar SH, Michelena HI, Li Z, Schaff HV, Sundt TM 3rd. Long-term risk of aortic events following aortic valve replacement in patients with bicuspid aortic valves. *Am J Cardiol* 2010;106(11):1626-33.

20. Sievers H, Stierle U, Mohamed S, et al. Toward individualized management of the ascending aorta in bicuspid aortic valve surgery: The role of valve phenotype in 1362 patients. *J Thorac Cardiovasc Surg* 2014;148(5):2072-80.

21. Nkomo VT, Enriquez-Sarano M, Ammash NM, et al. Bicuspid aortic valve associated with aortic dilatation: a community-based study. *Arterioscler Thromb Vasc Biol* 2003;23(2):351-6.

22. Cecconi M, Manfrin M, Moraca A, et al. Aortic dimensions in patients with bicuspid aortic valve without significant valve dysfunction. *Am J Cardiol* 2005;95(2):292-4.

23. Borger MA, Preston M, Ivanov J, et al. Should the ascending aorta be replaced more frequently in patients with bicuspid aortic valve disease? *J Thorac Cardiovasc Surg*. 2004;128(5):677-83.

24. Nishimura RA, Otto CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol*. 2014;63(22):2438-88.

25. Greason KL, Crestanello JA, King KS et al. Open hemiarch versus clamped

ascending aorta replacement for aortopathy during initial bicuspid aortic valve replacement. [published online September 25, 2019]. *J Thorac Cardiovasc Surg.* doi: 10.1016/j.jtcvs.2019.09.028

26. Baumgartner H, Falk V, Bax JJ, et al. 2017 ESC/EACTS guidelines for the management of valvular heart disease. *Eur Heart J.* 2017;38(36):2739–91.
27. Erbel R, Aboyans V, Boileau C et al. 2014 ESC Guidelines on the diagnosis and treatment of aortic diseases: Document covering acute and chronic aortic diseases of the thoracic and abdominal aorta of the adult. The Task Force for the Diagnosis and Treatment of Aortic Diseases of the European Society of Cardiology (ESC). *Eur Heart J.* 2014;35(41):2873-926.
28. Michelena HI, Suri RM, Katan O, et al. Sex Differences and Survival in Adults With Bicuspid Aortic Valves: Verification in 3 Contemporary Echocardiographic Cohorts. [published online September 29, 2016]. *J Am Heart Assoc.* doi: 10.1161/JAHA.116.004211

FIGURE LEGENDS

Figure 1:

A. Survival of patients with bicuspid aortic valve without a surgical indication at baseline compared to that of the age- and sex-matched general population.

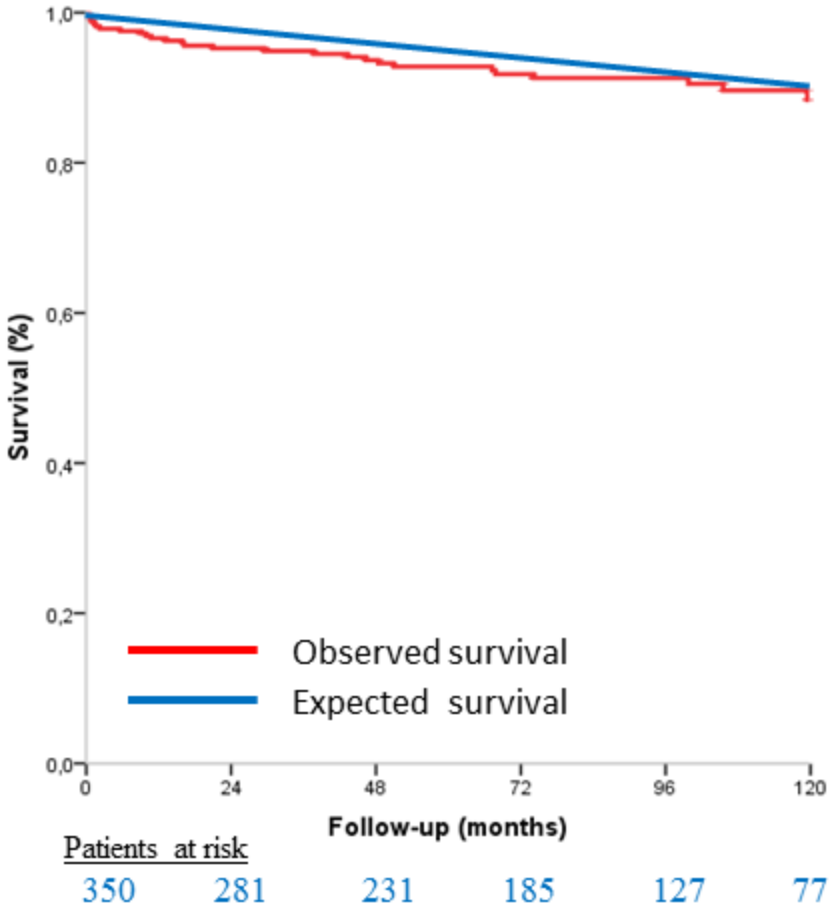
B. Survival of patients with bicuspid aortic valve with a surgical indication at baseline compared with that of the age- and sex-matched general population.

Figure 2:

Cumulative incidence of surgery during follow-up in the population of patients without a

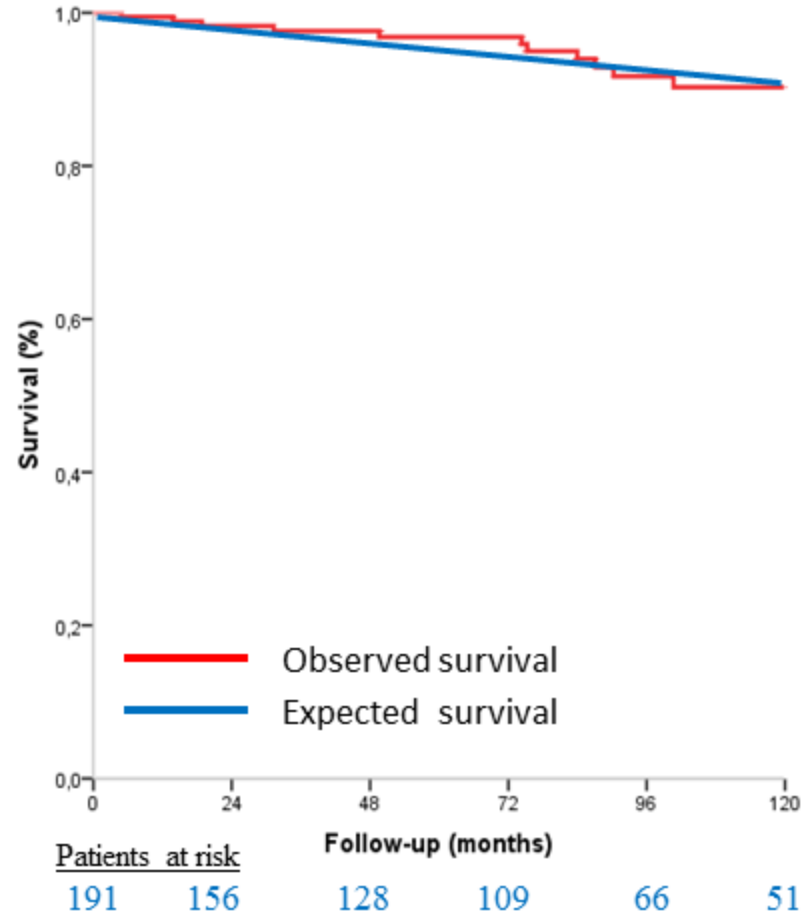
surgical indication at baseline

A

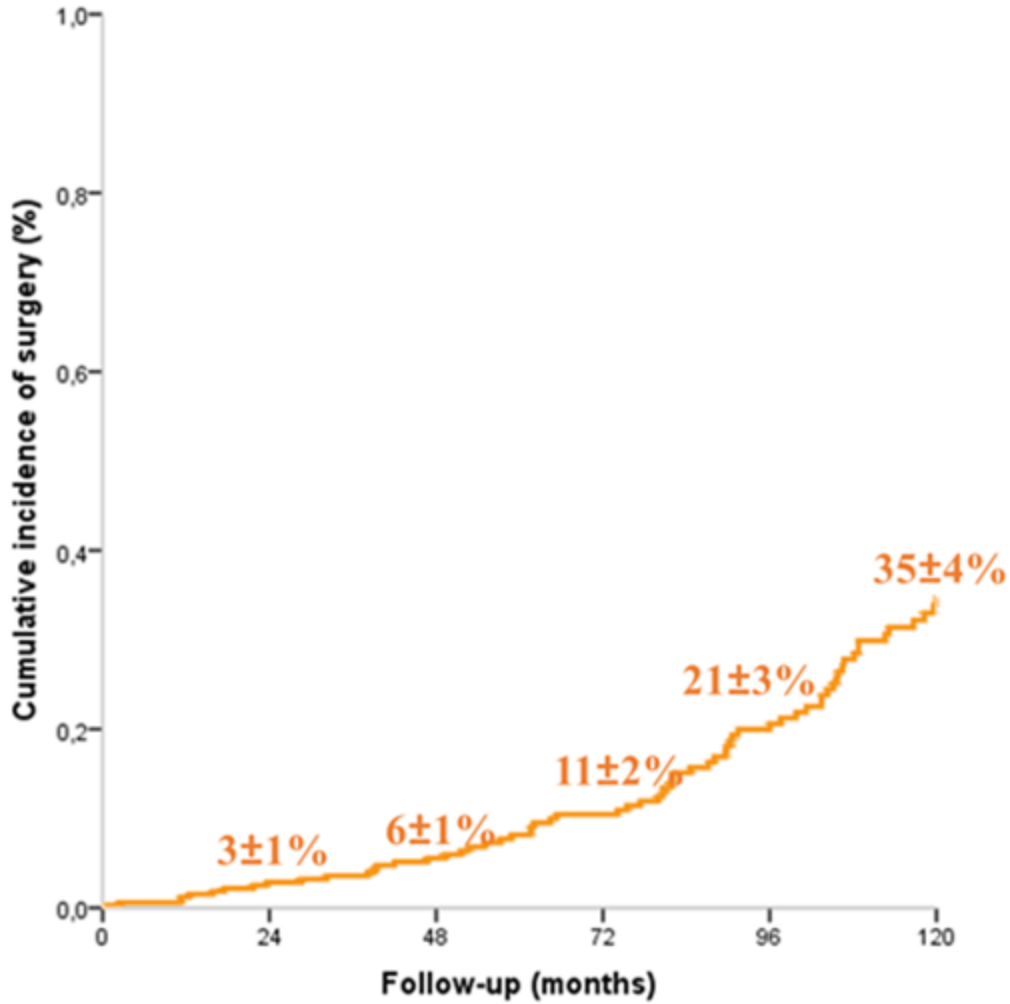


	24 months	48 months	72 months	96 months	120 months
Expected survival (%)	97.8	97.1	95.9	92.5	90
Observed survival (%)	96.1	94.5	92.2	91.5	88.8
Relative survival (%)	98.2	97.3	96.1	98.9	98.7

B



	24 months	48 months	72 months	96 months	120 months
Expected survival (%)	97.5	96.8	95	91.9	89.5
Observed survival (%)	97.4	97.1	96.1	91.5	89
Relative survival (%)	99.9	100.3	101.1	99.6	99.4



Patients at risk

350	281	231	185	127	77

Table 1: Baseline characteristics of the study population.

	Surveillance group (*n*=350)	**Surgical group (n=191)**
Age	53±16	59±13
18-45 years	*101 (28.8%)*	*19 (9.9%)*
45-65 years	*177 (50.6%)*	*109 (57.1%)*
>65 years	*72 (20.6%)*	*63 (33.0%)*
Male Sex	249(71.1%)	135(70.7%)
Weight(kg)	78±17	79±15
Size(cm)	171±8	170±9
Body mass index(kg/m²)	1.98±0.23	1.98±0.2
NYHA 1-2	333(95.1%)	149(78%)
NYHA 3-4	17(4.9%)*	42(22%)
Angina	29(8.2%)	30(15.7%)
Hypertension	164(46.8%)	110(57.6%)
Diabetes mellitus	48(13.7%)	21(11%)
Atrial fibrillation	21(6%)	10(5.2%)
Coronary artery disease	31(8.9%)	24(12.6%)
Charlson comorbidity index	1.14±1.7	1.12±1.4
Aortic stenosis	142 (40.6%)	125 (65.4%)
Aortic regurgitation	80 (22.9%)	26 (13.6%)
Ascending aorta dilatation>4cm	167 (47.7%)	114 (59.7%)
Valsalva sinus diameter (cm)	3.8±0.6	3.5±0.6
Ascending aorta diameter (cm)	3.8±0.7	4.2±0.9

Continuous variables are expressed as mean ± standard deviation (SD) and categorical variables as number and percentage.

AVA: aortic valve area; NYHA: New York heart association class

* 94% in stage III: 2 denied surgery, 7 underwent surgery>6 months after inclusion (patients' choice) and 8 had no indication for surgery but had associated chronic lung disease.

Table 2: Clinical and echocardiographic characteristics according to the valvular function in the surveillance group.

Variable	Normal or minimally dysfunctional aortic valve (*n*=128)	Aortic stenosis (*n*=142)	Aortic regurgitation (*n*=80)	p
Clinical and demographic characteristics				
Age(y)	48±15	59±15 [b]	50±16	**<.001**
Male Sex(n,%)	85(66.4%)	99(69.7%)	65(81.2%) [a]	**.03**
Body mass index(m²)	1.97±0.2	1.98±0.3	1.99±0.19	.83
NYHA(n,%)				
1-2	126(98.4%)	131(92.2%)	76(95%)	.10
3-4	2(1.6%)	11(7.8%) [a]	4(5%)	
Angina(n,%)	6(4.7%)	17(11.9%)	6(7.5%)	.06
Creatinine(µmol/l)	79±23	76±21	78±20	.22
Risk factor				
Hypertension(n,%)	45(35.2%)	85(59.9%) [a]	34(42.5%)	**.001**
Diabetes mellitus(n,%)	12(9.4%)	32(22.5%) [a]	4(5.0%)	**.001**
Coronary artery disease(n,%)	10(7.8%)	15(10.6%)	6(7.5%)	.70
Atrial fibrillation(n,%)	3(2.3%)	12(8.5%) [b]	6(7.5%) [a]	**<.001**
Charlson score	0.95±1.6	1.5±1.9	0.51±0.9	**<.001**
Logistic Euroscore(%)	2.6±2.2	5±8.9a	2.8±2	**.03**
Echocardiographic parameters				
Aortic valve and ascending aorta				
Sievers and Schmidtke classification				**.029**
Type 0	41 (32.0%)	27 (19.0%)	24 (30.0%)	
Type 1	86 (67.2%)	115 (81.0%)	54 (67.5%)	
Type 2	1 (0.8%)	0 (0.0%)	2 (2.5%)	
LVOT diameter(mm)	23±2.6	23±2.6	26±3 [b]	**<.001**
Aortic valve area(cm²)	2.7±0.6	1.1±0.4 [b]	2.7±1	**<.001**
Indexed aortic valve area(cm²/m²)	1.5±0.3	0.6±0.3 [b]	1.6±0.7	**<.001**
Aortic jet velocity(m/s)	1.7±0.5	3.5±1 [b]	2.2±1	**<.001**
Mean gradient(mmHg)	8±5	33±19 [b]	13±14	**<.001**
Aortic Valsalva sinuses(mm)	37±6	37±6	41±6 [a]	**<.001**
Proximal ascending aortic(mm)	37±7	38±7	41±7 [a]	**<.001**
Left ventricular function				
Left ventricular end-diastolic diameter(mm)	51±6	52±7	60±7 [b]	**<.001**
Left ventricular end-systolic diameter(mm)	32±6	33±8	39±7 [b]	**<.001**
Left ventricular ejection fraction(%)	64±6	63±11	59±9 [b]	**.006**
Left atrium area(cm²)	18±5	22±6 [b]	21±6 [a]	**.04**

Continuous variables are expressed as mean±standard deviation (SD) and categorical variables as number and percentage.

NYHA New York heart association class; AVA: aortic valve area; LVOT: left ventricular outflow tract

a: p<.05 each group versus normal or minimally dysfunctional aortic valve group
b: p<.001 each group versus normal or minimally dysfunctional aortic valve group.

Table 3: Surgical indications and surgical procedures of the study population according to initial management.

	Surveillance group (*n*=102)	**Surgical group (n=191)**
Surgical indications		
Aortic stenosis	47 (46%)	125 (65.5%)
Aortic regurgitation	27 (26.5%)	26 (13.5%)
Ascending aorta aneurysm	23 (22.5%)	40 (21%)
Infective endocarditis	5 (5%)	0 (0%)
Surgical procedures		
Isolated aortic valve replacement	60 (58.8%)	105 (55%)
Bioprosthetic valve	*24 (40%)*	*46 (44%)*
Mechanical valve	*36 (60%)*	*59 (66%)*
Bentall procedure	10 (9.8%)	18 (9.4%)
Bioprosthetic valve	*5 (50.0%)*	*9 (50%)*
Mechanical valve	*5 (50.0%)*	*9 (50%)*
Bentall + aortic arch replacement	*1 (1.0%)*	*2 (1%)*
Isolated aortic valve repair	5 (5%)	3 (1.6%)
AVR + supracoronary ascending aortic replacement	0 (0%)	21 (11%)
Isolated ascending aorta replacement	22 (21.5%)	32 (16.8%)
ascending aorta + aortic arch replacement	1 (1%)	3 (1.5%)
David or Yacoub surgery	0	5 (2.6%)
Ross procedure	3 (2.9%)	2 (1.1%)