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## Comparison of bicuspid and tricuspid aortic valve repair

Radosław Gocoł<sup>a</sup>, Jarosław Bis <sup>a,b</sup>, Marcin Malinowski <sup>a,b</sup>, Joanna Ciosek<sup>c</sup>, Damian Hudziak<sup>a</sup>,  
Łukasz Morkisz<sup>a</sup>, Marek Jasiński <sup>d</sup> and Marek A. Deja <sup>a,b,\*</sup>

<sup>a</sup> Department of Cardiac Surgery, Upper-Silesian Heart Center, Katowice, Poland

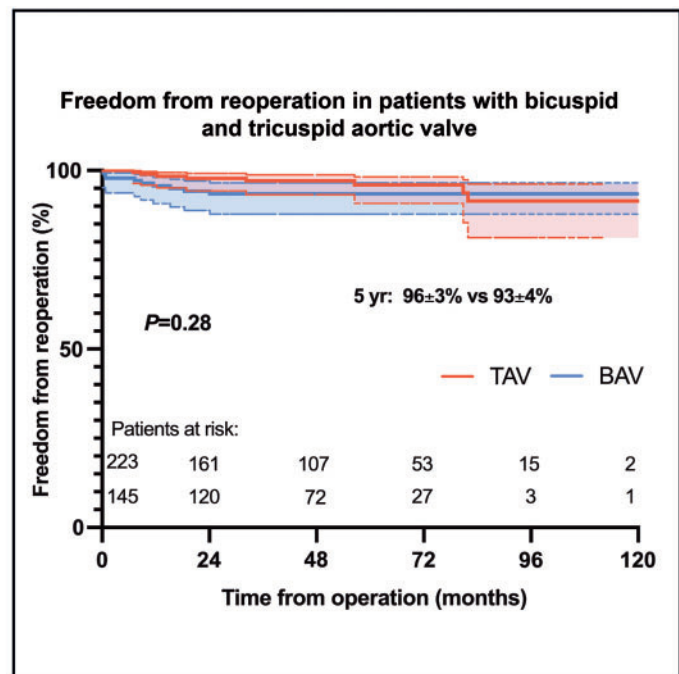
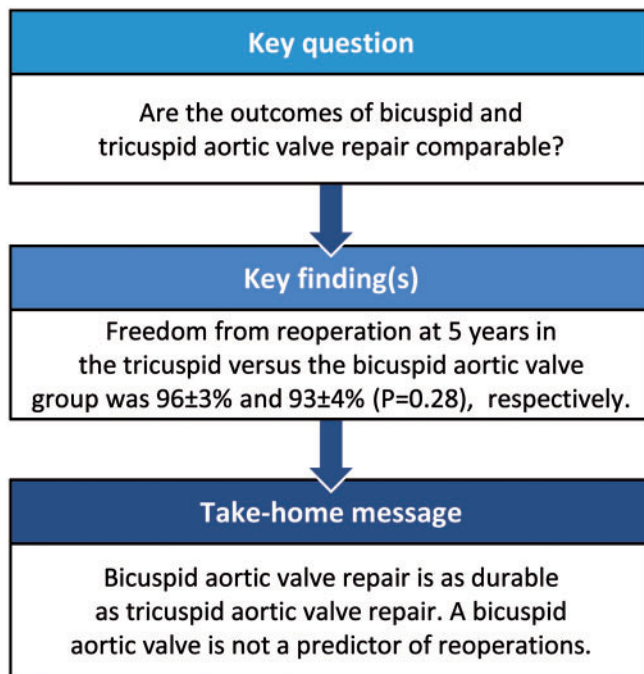
<sup>b</sup> Department of Cardiac Surgery, Medical University of Silesia, Faculty of Medical Sciences, Katowice, Poland

<sup>c</sup> 3rd Department of Cardiology, Upper-Silesian Heart Center, Katowice, Poland

<sup>d</sup> Department of Cardiac Surgery, Wrocław Medical University, Wrocław, Poland

\* Corresponding author. Department of Cardiac Surgery, Medical University of Silesia, ul. Ziołowa 45/47, Katowice 40-635, Poland. Tel: +48-323598644; e-mail: mdeja@sum.edu.pl (M.A. Deja).

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### Abstract

**OBJECTIVES:** The aim of this study was to compare the outcomes of tricuspid aortic valve (TAV) and bicuspid aortic valve (BAV) repair.

**METHODS:** We assessed mortality, freedom from reoperation and the rate of aortic valve regurgitation recurrence. Mortality in both groups was compared with expected survival, and risk factors for reoperation were identified.

**RESULTS:** From January 2010 to April 2020, a total of 368 elective aortic valve repair procedures were performed, including 223 (60.6%) in patients with TAV. The perioperative mortality was 0.7% in the BAV group and 3.6% in the TAV group (P=0.079). Estimated survival at 5 years in the BAV versus TAV group was 97 ± 3% vs 80 ± 6%, respectively (P < 0.001). Freedom from reoperation at 5 years in the TAV versus BAV group was 96 ± 3% vs 93 ± 4%, respectively (P = 0.28). Grade 2 or more aortic valve regurgitation was noted in 9.9% of BAV patients and 11% of TAV patients (P = 0.66). Reoperation was predicted by cusp perforation [hazard ratio 15.86 (4.44–56.61); P < 0.001], the use of pericardial patch [hazard ratio 8.58 (1.96–37.53); P = 0.004] and aortic valve annulus diameter >27.5 mm [hazard ratio 3.07 (0.99–9.58); P = 0.053].

**CONCLUSIONS:** BAV repair is as durable as TAV repair. BAV is not a predictor of a higher rate of reoperations. BAV repair yields survival comparable to expected. Cusp perforation, aortic valve annulus diameter >27.5 mm and the use of pericardial patch adversely impact long-term outcome of aortic valve repair.

**Keywords:** Aortic valve repair • Bicuspid aortic valve • Tricuspid aortic valve

#### ABBREVIATIONS

BAV	Bicuspid aortic valve
PTFE	Polytetrafluoroethylene
ROC	Receiver operating characteristic
TAV	Tricuspid aortic valve

## INTRODUCTION

Aortic valve repair has recently evolved into a reliable and reproducible cardiac surgical technique, receiving class I recommendation in the current guidelines, thus providing an alternative to aortic valve replacement [1]. The growing knowledge on the mechanisms of tricuspid aortic valve (TAV) and bicuspid aortic valve (BAV) regurgitation has significantly contributed to the development of aortic valve reconstructive surgery [2, 3]. Surgical research groups led by David, ElKhoury and Schaffers proved the complex approach to aortic valve as a key prerequisite for successful repair [4–6]. Accordingly, aortic valve repair should be performed at 4 levels: aortic annulus, aortic valve cusps, aortic root and sinotubular junction. The implementation of these general principles in clinical practice greatly improved the outcomes of aortic valve reconstructive surgery and allowed for the identification of specific predictors of durable aortic valve repair [7]. The aim of our study was to compare the outcomes of regurgitant aortic valve repair in patients with BAV and TAV.

## METHODS

The local Institutional Review Board opinion was requested. They decided that the follow-up was not a medical experiment, and therefore, their approval was not required (decision number KNW/0022/KB/284/17 dated 12 December 2017).

The analysis included all consecutive patients who had undergone elective aortic valve reconstructive surgery at the Department of Cardiac Surgery, Upper Silesian Heart Center of the Medical University of Silesia in Katowice, Poland, from January 2010 to April 2020.

Patients with coexisting heart disease, requiring additional surgical procedures, were not excluded. However, excluded were patients with acute type A aortic dissection undergoing emergency surgery.

We assessed mortality, freedom from reoperation, and the rate of aortic valve regurgitation in 2 groups: patients with TAV and patients with BAV.

The mortality and freedom from reoperation status were ascertained from 1 or more of the following: patient's visit in the outpatient clinic, telephone contact with the patient or patient's relatives, National Registry of Cardiac Surgical Procedures (Krajowy Rejestr Operacji Kardiologicznych) ([www.krok.csioz.gov.pl](http://www.krok.csioz.gov.pl)) Krajowy Rejestr Operacji Kardiologicznych registry contains the mortality data obtained from the National Health

Fund (Narodowy Fundusz Zdrowia). Death from all causes was included into the analysis.

The outcome of aortic valve repair was assessed by echocardiography. Aortic insufficiency was classified according to the 4-grade scale: 0, none or trivial; 1, mild; 2, moderate; 3, moderately severe; 4, severe [8, 9].

## Operative technique

The patients selected for aortic valve repair were generally those with pliable leaflets and little calcification. The need to replace big areas of leaflets with pericardial patch was considered a contraindication for valve sparing procedure. Similarly, we did not repair valves with active aortic endocarditis. However, the need for additional procedures (coronary artery bypass surgery or mitral valve repair) and clinical characteristics including low ejection fraction or age were not a contraindication for aortic valve repair.

We used median sternotomy access. Cardiopulmonary bypass (CPB) was established in normothermic conditions. One of the 3 types of cardioplegic regimens was used: cold del Nido cardioplegic solution, cold blood cardioplegic solution (4:1 ratio) and miniplegia.

The following techniques were used for aortic valve repair and aortic annulus stabilization: external stabilization with polytetrafluoroethylene (PTFE) suture [10] or Dacron graft ring (full or semicircular) [11], internal stabilization: with Cabrol stitch (sub-commissural plication) [12], PTFE suture [13] or rigid HAART 300 ring (BioStable Science and Engineering, Austin, TX) [14]. The following techniques were used for aortic valve cusp repair: central plication, free edge plication with the use of PTFE suture, cusp reconstruction with pericardial patch, cusp shaving and decalcification [15, 16]. In case of coexisting aortic root aneurysm, the aortic valve sparing operation was performed, either aortic valve reimplantation using the David method [17] (Video 1) or aortic root remodelling using the Yacoub method [18]. When aneurysm of the ascending aorta or aortic arch was present, it was excised and replaced by the Dacron aortic graft, thus remodelling the sinotubular junction. In some patients, the remodelling of sinotubular junction was the only indication for the replacement of ascending aorta [19].

## Statistical analysis

Data are presented as mean and standard deviation when normally distributed or as median with 25th and 75th percentiles when normality assumption (Shapiro–Wilk test) was not met. Categorical data are expressed as a percentage. The comparisons between BAV and TAV group were carried out with the use of *t*-test or Mann–Whitney test depending on data distribution. Chi-square test or Fisher's exact test was used to determine whether frequencies differed between the study groups. Kaplan–Meier time-to-event curves were generated. Groups were compared with log-rank (Mantel–Cox) test. Mortality in both groups was

compared with expected survival in these groups. Expected survival curves for both analyzed groups adjusted for age and gender were constructed on the basis of 'Average life expectancy tables' published by the Central Statistical Office (<https://stat.gov.pl/obszary-tematyczne/ludnosc/trwanie-zycia/trwanie-zycia-tablice,1,1.html> last accessed 20th June, 2020) according to method described by Finkelstein *et al.* [20]. The 5-year survival/freedom from reoperation was estimated and reported with the standard error. The predictors of reoperation were identified by univariable Cox regression. The proportionality assumption was tested with time-dependent Cox analysis examining the interaction of the product of time and the variable in question with the variable itself. As the aortic annulus diameter was not normally distributed, we dichotomized this variable using time-dependent receiver operating characteristic (ROC) curve analysis to find the best cut-off value. Due to the low variability in dependent variable (reoperation), the time-dependent ROC was performed for whole period of time between 0 and 10 years with step by 1 year. The variables with score statistics  $P$ -value  $<0.1$  were included into multivariable analysis. Due to the small number of events we performed separate analyses containing each

time selected variable and a variable of interest, i.e. the presence of the BAV. The statistical analysis was performed with IBM SPSS v26 (IBM Corp. Armonk, NY), SAS 9.4 (SAS Institute Inc., Cary, NC, USA) and MedCalc version 19.4.1 (MedCalc Software Ltd.). The survival analysis was done in GraphPad Prism ver. 8.4 (GraphPad Software, San Diego, CA).  $P$ -value  $<0.05$  was considered statistically significant.

## RESULTS

During the study period, a total of 368 elective aortic valve repair procedures were performed, including 223 (60.6%) in patients with TAV. Baseline demographic data of the study population are summarized in Table 1.

Patients with BAV were significantly younger than those with TAV, 41 years (IQR: 31; 56.5) vs 64 years (57; 71) ( $P < 0.001$ ). Significantly less comorbidities were noted in the BAV group in comparison to the TAV group, which was reflected by the lower EuroSCORE II: 2.48 (1.21; 3.74) vs 3.56 (2.08; 6.57) ( $P < 0.001$ ) (Table 1).

**Table 1:** Clinical and echocardiographic characteristics

Variable	All, n = 368	TAV, n = 223	BAV, n = 145	P-value
<b>Clinical data</b>				
Sex (male) (%)	271 (73.6)	148 (66.4)	123 (84.8)	<0.001
Age (years)	59 (40; 68)	64 (57; 71)	41 (31; 56.5)	<0.001
BMI	26.8 (24.1; 29.8)	27.1 (24.2; 30.3)	26.4 (24.0; 29.2)	0.30
NYHA (%)	n = 359	n = 219	n = 140	0.026
I	114 (31.8)	62 (28.3)	52 (37.1)	
II	183 (51.0)	109 (49.8)	74 (52.9)	
III	57 (15.9)	44 (20.1)	13 (9.3)	
IV	5 (1.4)	4 (1.8)	1 (0.7)	
Coronary artery disease (%)	73 (19.8)	63 (28.2)	10 (6.9)	<0.001
At least moderate mitral regurgitation (%)	68 (18.6)	59 (26.7)	9 (6.7)	<0.001
At least moderate tricuspid regurgitation (%)	18 (4.9)	17 (7.6)	1 (0.6)	0.006
Aortic root aneurysm (%)	99 (26.9)	60 (26.9)	39 (26.9)	0.97
Ascending aorta aneurysm (%)	161 (43.7)	94 (42.1)	67 (46.2)	0.51
Arterial hypertension (%)	269 (73.3)	183 (82.0)	86 (59.6)	<0.001
Atrial fibrillation (%)	56 (15.3)	49 (21.9)	7 (5.0)	<0.001
Diabetes mellitus (%)	35 (9.5)	30 (13.2)	5 (3.6)	0.002
Chronic renal failure (%)	32 (8.7)	22 (9.8)	10 (6.8)	0.008
EuroSCORE II	2.95 (1.77; 5.06)	3.56 (2.08; 6.57)	2.48 (1.21; 3.74)	<0.001
<b>Echocardiographic data (n = 349)</b>				
Aortic regurgitation grade (number of patients) (%)	n = 349	n = 204	n = 145	<0.001
0	41/349 (11.7)	8/204 (3.9)	10/145 (6.9)	
1	28/349 (8.0)	14/204 (6.9)	14/145 (9.7)	
2	50/349 (14.3)	37/204 (18.1)	13/145 (9.0)	
3	116/349 (33.2)	74/204 (36.3)	33/145 (22.8)	
4	151/349 (43.2)	71/204 (34.4)	75/145 (51.7)	
LVOT (mm)	24 (20; 26)	22.5 (20; 24.8)	26 (23; 30)	<0.001
	n = 183	n = 116	n = 67	
Aortic annulus (mm)	27 (24; 29)	25 (23; 27)	28 (26; 31)	<0.001
	n = 292	n = 165	n = 127	
Aortic root (mm)	42 (37; 47)	42 (36; 50)	42 (38; 45)	0.66
	n = 318	n = 186	n = 132	
Ascending aorta (mm)	46 (37; 52)	46 (37; 54)	44 (36; 50)	0.027
	n = 324	n = 192	n = 132	
EF (%)	55 (50; 60)	55 (48; 59)	55 (50; 60)	0.16
	n = 333	n = 195	n = 138	
EDV (ml)	187 (147; 250)	187 (147; 218)	217 (160; 286)	0.002
	n = 282	n = 169	n = 113	

Data are presented as median (25th to 75th percentiles).

BAV: bicuspid aortic valve; BMI: body mass index; EDV: end diastolic volume; EF: ejection fraction; LVOT: left ventricular outflow tract; NYHA: New York Heart Association; TAV: tricuspid aortic valve.

Moreover, significantly more patients from the TAV group had an additional cardiac surgical procedure performed, apart from the intervention involving the aortic complex [134 (60.1%) vs 19 (13.1%),  $P < 0.001$ ] (Table 2).

In both study groups, all available surgical techniques for aortic valve reconstruction were used, involving interventions at different levels of the aortic complex (Table 2).

The comparison of perioperative data revealed significantly longer cardiopulmonary bypass time of 104 min (78.5; 146) in

the TAV group in relation to 93 min (72.5; 126) in the BAV group ( $P = 0.035$ ). Patients with TAV had longer ventilation times, 13.6 h (11.2; 19.9) vs 10.6 h (8.4; 13.6) ( $P < 0.001$ ) and more extended hospital stay, 8 days (7; 11) vs 7 days (7; 8) ( $P < 0.001$ ) in comparison to patients with BAV (Table 3).

The postoperative complication rate was similar in both study groups; however, postoperative acute renal failure was noted in 3.1% of patients with TAV and in no patient with BAV ( $P = 0.031$ ) (Table 3).

**Table 2:** Surgery scope

Variable	All, n = 368	TAV, n = 223	BAV, n = 145	P-value
External aortic annuloplasty (%)	60 (16.3)	7 (3.1)	53 (36.6)	<0.001
PTFE suture	3 (0.8)	2 (0.9)	1 (0.7)	0.71
Full ring	11 (3.0)	0	11 (7.6)	<0.001
Semi ring	46 (12.5)	5 (2.3)	41 (28.3)	<0.001
Internal aortic annuloplasty (%)	162 (44)	117 (52.4)	45 (31)	<0.001
Cabrol stitch	123 (33.4)	95 (42.6)	28 (19.3)	<0.001
HAART 300™ ring	20 (5.4)	20 (9.0)	0	<0.001
PTFE suture	19 (5.2)	2 (0.9)	17 (11.7)	<0.001
Aortic cusp correction (%)	218 (59.2)	84 (37.7)	134 (92.4)	<0.001
Central plication	180 (48.9)	63 (28.2)	117 (80.7)	<0.001
Free edge plication	9 (2.4)	6 (2.7)	3 (2.0)	0.98
Pericardial patch	5 (1.4)	2 (0.9)	3 (2.1)	0.34
Resection	29 (7.9)	0	29 (20)	<0.001
Decalcification	29 (7.9)	15 (6.7)	14 (9.7)	0.31
Fenestration closure	2 (0.3)	1 (0.4)	1 (0.7)	0.76
Shaving	58 (15.8)	6 (2.7)	52 (36.5)	<0.001
Replacement of the aorta (%)				
VSARR	99 (27)	60 (27)	39 (27)	1.0
Reimplantation (David method)	51 (13.9)	25 (11.2)	26 (17.9)	0.068
Remodelling (Yacoub method)	48 (13.0)	35 (15.7)	13 (9.0)	0.086
Ascending aorta	161 (43.8)	94 (42.2)	67 (46.2)	0.44
STJ remodelling	56 (15.3)	33 (15.0)	23 (16.0)	0.80
Aortic arch (%)	19 (5.2)	16 (7.2)	3 (2.1)	0.072
CABG (%)	73 (19.8)	63 (28.2)	10 (6.9)	<0.001
Mitral valve repair (%)	57 (15.5)	50 (22.4)	7 (4.8)	<0.001
Tricuspid valve repair (%)	18 (4.9)	17 (7.6)	1 (0.6)	0.006
AF Ablation–maze IV (%)	5 (1.3)	4 (1.8)	1 (0.6)	0.67

Data are presented as n (%).

AF: atrial fibrillation; BAV: bicuspid aortic valve; CABG: coronary artery bypass graft; PTFE: polytetrafluoroethylene; STJ: sinotubular junction; TAV: tricuspid aortic valve; VSARR: valve sparing aortic root replacement.

**Table 3:** Surgery data and complications

Parameter	All (n = 368)	TAV (n = 223)	BAV (n = 145)	P-value
Early mortality (%)	9 (2.4)	8 (3.6)	1 (0.7)	0.079
X-clamp (min)	76.5 (57; 104)	79 (56; 104.5)	74 (57; 100.5)	0.98
CPB (min)	100 (77; 139)	104 (78.5; 146)	93 (72.5; 126)	0.035
Drainage (ml)	700 (500; 905)	710 (500; 1096)	670 (525; 815)	0.091
Ventilation time (h)	12.5 (9.4; 16.5)	13.6 (11.2; 19.9)	10.6 (8.4; 13.6)	<0.001
Hospital stay (days)	8 (7; 10)	8 (7; 11)	7 (7; 8)	<0.001
Resternotomy for bleeding (%)	35/294 (11.9)	24/174 (13.8)	11/120 (9.2)	0.23
Cardiac tamponade (%)	8/368 (2.2)	4/223 (1.8)	4/145 (2.8)	0.54
Stroke (%)	12/368 (3.3)	9/223 (4.0)	3/145 (2.1)	0.30
Renal failure (%)	7/368 (1.9)	7/223 (3.1)	0	0.031
Pneumonia (%)	11/368 (3)	8/223 (3.6)	3/145 (2.1)	0.40
Wound infection (%)	3/368 (0.8)	2/223 (0.9)	1/145 (0.7)	0.83
Permanent pacemaker implantation (%)	8/368 (2.2)	4/223 (1.8)	4/145 (2.8)	0.54

Data are presented as median (25th to 75th percentiles).

BAV: bicuspid aortic valve; CPB: cardiopulmonary bypass; TAV: tricuspid aortic valve.

The analysis contains data on mortality and freedom from reoperation from all (100%) patients included in the study.

The perioperative mortality (30 day) was 0.7% (1 patient) in the BAV group and 3.6% (8 patients) in the TAV group ( $P=0.079$ ).

The median follow-up period was 48.2 months (26.4; 69.8).

We observed 2 deaths in BAV patients and 32 deaths in TAV patients during follow-up. Estimated 5-year survival was  $97 \pm 3\%$  in the BAV group and  $80 \pm 6\%$  in the TAV group ( $P < 0.001$ , log-rank test) (Fig. 1A).

The survival of patients with BAV who underwent aortic valve repair was similar to the expected survival for respective age and gender (Fig. 1A). Conversely, in patients with TAV, the surgery failed to restore the expected survival.

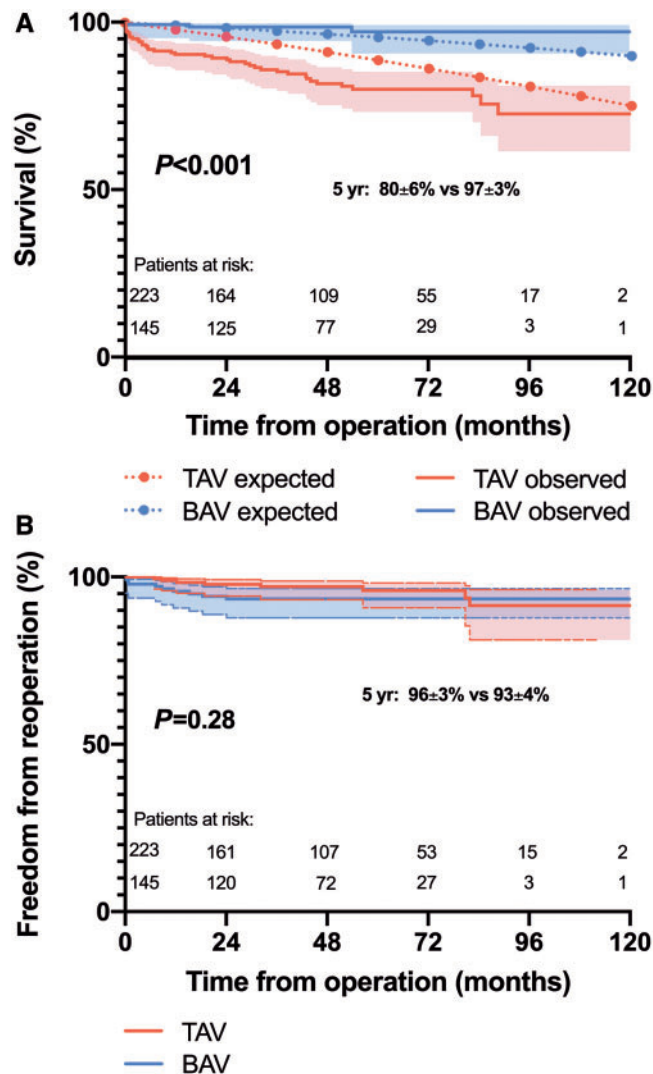
Seventeen patients (4.6%) underwent reoperation during the follow-up period. In 14 (3.8%) of these patients, reoperation of the aortic valve was performed (10 patients for recurrence of aortic valve regurgitation, 3 patients for aortic valve stenosis and 1 patient for aortic root aneurysm) including 8 patients (3.6%) from the TAV group and 9 patients (6.2%) from the BAV group. In 3

(0.8%) patients, the reoperation did not involve the aortic valve (in 2 mitral valve replacement was performed and in 1 descending aorta was replaced). The estimated 5-year freedom from reoperation was  $93 \pm 4\%$  in the BAV group and  $96 \pm 3\%$  in the TAV group ( $P=0.28$ , log-rank test) (Fig. 1B).

BAV was not associated with the increased risk of reoperation in neither univariable nor multivariable analysis (Tables 4 and 5). Among morphological features, cusp perforation was an independent predictor of reoperation (Table 4). The aortic annulus diameter was dichotomized using the time-dependent ROC. The optimal cut-off value associated with the Youden index [21] was 27.86 mm. The annulus diameter  $>27.5$  mm tended to predict reoperation hazard ratio 3.07 (0.99–9.58);  $P=0.053$  (Fig. 2). Among different surgical techniques, the only one associated with reoperation was pericardial patch repair of aortic leaflet (Table 4).

At least 1 postoperative echocardiographic study was performed in 361 patients (98.1%) during the follow-up period (in all BAV patients and in 97% of TAV patients,  $P=0.03$ ).

The mean time from surgery to follow-up echocardiography in the BAV group was  $24.1 \pm 24.7$  months and in the TAV group  $20.2 \pm 28$  months ( $P=0.16$ ). We observed grade 2 or bigger aortic valve regurgitation on echocardiography in 14 (9.9%) of the BAV and 24 (11%) of the TAV patients ( $P=0.66$ ) (Fig. 3).



**Figure 1:** Kaplan-Meier curves. **(A)** Survival of patients with bicuspid and tricuspid aortic valve. **(B)** Freedom from reoperation in patients with bicuspid and tricuspid aortic valve. Kaplan-Meier curves with 95% confidence interval. Estimated 5-year survival/freedom from reoperation is given with standard error.  $P$  from log-rank (Mantel-Cox) test.

## DISCUSSION

Despite the fact that aortic valve replacement still represents the ‘gold standard’ in surgical approach to aortic valve regurgitation, reconstructive surgery of aortic valve is increasingly performed

**Table 4:** Univariable analysis of risk factors of reoperation

Risk factors	Univariable analysis	
	HR (95% CI)	P value
<b>Morphological features</b>		
BAV	1.66 (0.64–4.31)	0.30
<b>Cusp</b>		
Prolapse	1.31 (0.50–3.40)	0.58
Fenestration	0.05 (0.00–5850.16)	0.61
Calcification	1.21 (0.28–5.30)	0.80
Retraction	0.05 (0.00–6266.28)	0.67
Perforation	14.08 (4.01–49.45)	<b>&lt;0.001</b>
Aortic annulus $>27.5$ mm	2.99 (1.00–8.93)	<b>0.050</b>
<b>Surgical techniques</b>		
Aortic valve repair	1.66 (0.63–4.37)	0.30
STJ remodelling	0.83 (0.32–2.19)	0.71
VSARR	0.63 (0.18–2.21)	0.47
Yacoub procedure	0.04 (0.00–29.84)	0.34
David procedure	1.32 (0.38–4.60)	0.66
<b>Cusp correction</b>		
Central plication	1.21 (0.47–3.15)	0.69
Resection	1.52 (0.35–6.65)	0.58
Free edge plication	1.74 (0.23–13.20)	0.59
Decalcification	1.38 (0.32–6.04)	0.67
Pericardial patch	8.93 (2.03–39.39)	<b>0.004</b>
Shaving	0.92 (0.26–3.29)	0.90
<b>Aortic annuloplasty</b>		
External	0.61 (0.14–2.67)	0.51
Internal	0.96 (0.13–7.41)	0.97
Cabrol stitch	1.51 (0.58–3.93)	0.40

BAV: bicuspid aortic valve; CI: confidence interval; HR: hazard ratio; STJ: sinotubular junction; VSARR: valve sparing aortic root replacement.

and has become a viable option both for patients with BAV and TAV [22]. This development was made possible with better understanding of the mechanisms and patterns of aortic valve regurgitation [2, 3], which improved the long-term outcomes of

aortic valve repair [4, 23]. In the literature to date there is a lack of direct comparisons of long-term aortic valve repair outcomes in patients with TAV and BAV. Most studies focus on the assessment of repair outcomes either in the TAV or BAV group. In this study, we compared the outcomes of aortic valve repair in patients with BAV and TAV.

Our analysis has demonstrated excellent outcomes of aortic valve repair both in patients with TAV and BAV, comparable to those published by other groups specializing in the reconstructive surgery of aortic valve. Our 5-year survival for BAV patients was  $97 \pm 3\%$ , whereas for TAV patients it was  $80 \pm 6\%$ . The difference in survival results most likely from the younger age and less co-morbidities in BAV patients. Svensson et al. [24] from Cleveland Clinic analyze a large cohort of 728 BAV patients and report a 5-year and 10-year survivals of 97% and 94%, respectively, which are close to our results. On the other hand, in TAV repair, de Kerchove et al. [25] report a 8-year survival of  $80 \pm 5\%$  in the cohort of 382 patients.

There is evidence in current literature, demonstrating that mitral valve repair restores expected survival [26]. However, such reports on aortic valve repair are lacking. Therefore, we compared the survival curves from the study with expected survival curves. We found that similarly to mitral valve repair, aortic valve repair in patients with BAV restores expected survival. Conversely, in patients with TAV, valve repair failed to restore expected survival. Most likely, it was the consequence of significant differences between BAV and TAV patients. The BAV patients were generally young with aortic complex disease as the only reason for operative treatment. Those with TAV were older and had more co-morbidities, which substantially affected their prognosis. For instance, 59 patients in the TAV group had MV regurgitation, which was severe in as many as 42. We performed MV repair in 50 patients. We are aware that this additional mitral procedure could have increased the operative risk and early mortality and the mitral regurgitation could have affected long-term prognosis in the TAV group. This was reflected by the significantly higher EuroScore II.

**Table 5:** Multivariable analyses of risk factors of reoperation

Risk factors	Multivariable analysis	
	HR (95% CI)	P-value
BAV	2.18 (0.84–5.67)	0.11
Cusp perforation	15.86 (4.44–56.61)	<0.001
BAV	1.88 (0.74–4.79)	0.19
Pericardial patch	8.58 (1.96–37.53)	0.004
BAV	1.27 (0.42–3.79)	0.67
Aortic annulus >27.5 mm	3.07 (0.99–9.58)	0.053

BAV: bicuspid aortic valve; CI: confidence interval; HR: hazard ratio.

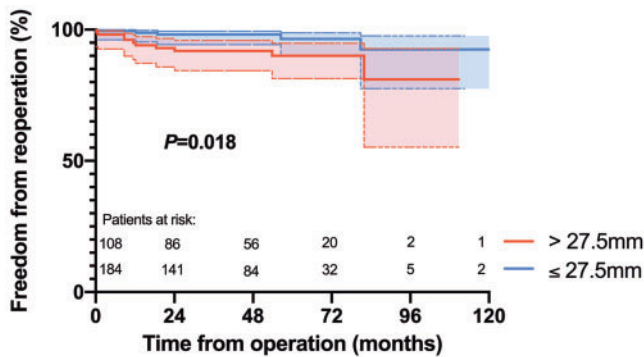


Figure 2: Influence of aortic annulus diameter on hazard of reoperation. Kaplan-Meier curves with 95% confidence interval. Estimated 5-year freedom from reoperation is given with standard error. P from log-rank (Mantel-Cox) test.

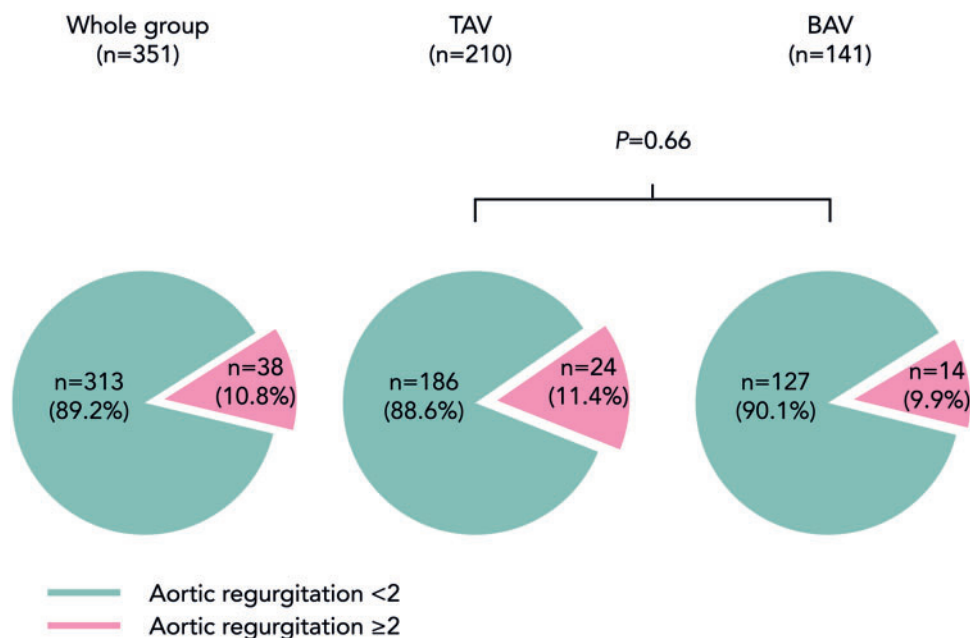
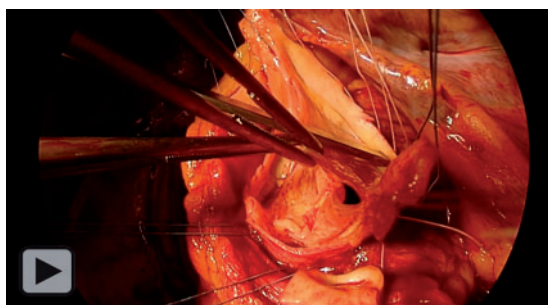


Figure 3: Rate of aortic valve regurgitation.



**Video 1:** Bicuspid aortic valve reimplantation using the David method.

The durability of repair in our cohort has been confirmed by the low ratio of patients requiring reintervention. In the BAV group, the 5-year freedom from reintervention was  $93 \pm 4\%$ , whereas in the TAV group, these rates were  $96 \pm 3\%$  ( $P=0.28$ ). Patients with BAV more frequently underwent complicated repair involving several levels of the aortic complex (aortic annulus, aortic cusps, aortic root, sinotubular junction). For reference, in as many as 46.2% of TAV patients, the intervention at only one of the particular levels (aortic annulus, aortic cusps, aortic root, sinotubular junction) was sufficient to achieve valve competency. These data confirm that BAV repair is more surgically demanding in comparison to TAV repair, but both yield similar outcomes with regards to durability. In BAV patients, a repair addressing all levels of the aortic complex ensures excellent long-term freedom from reintervention.

Our analysis includes a variety of surgical techniques used for aortic annulus stabilization. This is the consequence of the fact that aortic valve repair procedures were performed over 10 years by several surgeons, who had used their own preferred techniques. Moreover, the surgical state-of-the-art in aortic valve repair changed over these 10 years. Both univariable and multivariable analyses performed in our study failed to identify the most effective surgical method for stabilizing the aortic annulus. On the basis of our experience, however, in isolated aortic annulus enlargement, we recommend both the internal and external annuloplasty with the exclusion of the Cabrol stitch, whereas for addressing the enlargement of both aortic annulus and aortic root, we advocate the reimplantation of the aortic valve using the David technique.

As to BAV patients, Aicher *et al.* [27] report 5-year freedom from the reintervention rate of 88% and the 10-year rate of 81%, whereas Ram *et al.* [28] identify BAV as an independent risk factor for reintervention. In the TAV patients, our results are similar to those published by de Kerchove *et al.* [25], who report freedom from reintervention of  $92 \pm 5\%$ .

Majority of our patients had no recurrence of aortic valve regurgitation on last echocardiogram (88.6% TAV and 90.1% BAV patients). While our BAV results do not diverge from other published data (Fattouch *et al.* [29] report freedom from aortic valve regurgitation recurrence in 93% of patients), the 11% recurrence of significant aortic valve regurgitation in the TAV group is remarkable. For reference, de Kerchove *et al.* [25] report freedom from aortic valve regurgitation recurrence in only 71% of patients. Still it may be related to relatively short median time from operation to echocardiography in our group.

Our study shows that patients with TAV and BAV undergoing aortic valve repair are very different. However, having analyzed our data we conclude that the number of aortic valve cusps does

not impact long-term outcome of the repair as long as the repair is performed in the complex and systematic fashion. Even though BAV repair is more technically demanding, thanks to the aggressive and preventive approach to the aortic complex at all its levels we were able to obtain results, which are not different to TAV repair, and BAV was not a predictor of increased reoperation rate. BAV repair yields survival comparable to expected. Of note, cusp perforation, aortic annulus diameter  $>27.5$  mm and the use of pericardial patch adversely impact the long-term outcomes of repair.

## Limitations

The present study is a retrospective analysis with unbalanced patient numbers in the 2 groups. At least 1 echocardiographic study was performed in 361 patients (98.1%) during the follow-up period to ascertain the freedom from aortic valve regurgitation. However, due to retrospective nature and inclusion of all consecutive patients including very recent surgery, we lack systematic echocardiographic follow-up and the median time from surgery to echocardiography is  $<2$  years. It is therefore possible that the long-term echocardiographic data are less optimal. On the other hand, the valve that is competent at 2 years will likely remain functional long term. Still the over 90% freedom from reoperation appears highly reassuring.

## CONCLUSION

BAV repair is as durable as TAV repair. BAV is not a predictor of a higher rate of reoperations. BAV repair yields survival comparable to expected. Cusp perforation, aortic valve annulus diameter  $>27.5$  mm and the use of pericardial patch adversely impact the long-term outcome of aortic valve repair.

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## Author contributions:

**Radosław Gocoł:** Conceptualization; Data curation; Investigation; Methodology; Writing—original draft; Writing—review & editing. **Jarosław Bis:** Investigation; Writing—original draft; Writing—review & editing. **Marcin Malinowski:** Conceptualization; Data curation; Formal analysis; Investigation; Validation; Writing—review & editing. **Joanna Ciosek:** Investigation; Writing—review & editing. **Damian Hudziak:** Investigation; Writing—review & editing. **Łukasz Morkisz:** Visualization; Writing—review & editing. **Marek Jasiński:** Data curation; Investigation; Writing—review & editing. **Marek A. Deja:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology;

Project administration; Resources; Supervision; Validation; Writing–review & editing.

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