ORIGINAL ARTICLE

Long-term outcomes of aortic valve repair in over 500 consecutive patients: a single-center experience

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KEY WORDS
aortic valve regurgitation, aortic valve repair, aortic valve sparing procedures

EDITORIAL
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ABSTRACT

BACKGROUND Over the last years, aortic valve repair has evolved from being a random and irreproducible procedure to a standardized technique yielding durable long-term results.

AIMS The aim of the study was to assess long-term outcomes of aortic valve repair and aortic valve sparing procedures.

METHODS We analyzed the outcomes of all consecutive patients who underwent aortic valve repair and / or aortic valve sparing root replacement till the end of 2019. We assessed mortality, freedom from reoperation, and freedom from at least moderate aortic valve regurgitation.

RESULTS A total of 504 patients underwent aortic valve repair and / or aortic valve sparing root replacement over 17 years, including 452 (89.7%) elective and 52 (10.3%) emergency surgeries for acute type A aortic dissections. Median (interquartile range) age was 59 (35–66) years, 72.4% were male. Median follow-up time was 35 months. Estimated 5-year survival was 83%, and 10-year survival was 73%. In 452 patients after elective surgery, the estimated actuarial 5-year and 10-year survival was 86% and 75%, respectively. In patients after emergency surgery for acute type A aortic dissection, actuarial 5-year survival was 62%, and 10-year survival was 62%. Estimated 5- and 10-year freedom from reoperation was 96% and 87%, respectively. The comparison of both subgroups did not reveal differences (P = 0.42). Freedom from at least moderate aortic valve regurgitation was confirmed in 86.6% of patients.

CONCLUSIONS Aortic valve repair is a durable and effective surgical procedure associated with low early and late mortality. Aortic valve reconstruction in patients with acute type A aortic dissection yields good long-term results.

INTRODUCTION Over the last years, aortic valve repair has evolved from being a random and irreproducible procedure to a standardized technique yielding durable long-term results.[1] The interest in aortic valve repair is constantly growing and the aortic valve sparing procedures, originally introduced by David and Yacoub, are performed more often.[2,3] Techniques of cusp repair, such as central plication, have become standardized procedures which contribute significantly to the improvement of long-term repair outcomes.[4,5] Another important development in the aortic valve surgery includes the introduction of aortic valve regurgitation classification, standardization of echocardiographic assessment, and better understanding of bicuspid aortic valve anatomy and hemodynamics.[6-8] Moreover, steady improvement of aortic valve repair techniques enabled the identification of repair durability predictors.[9,10]

The aim of this study was to analyze the outcomes of aortic valve repair.

METHODS We analyzed the outcomes of all consecutive patients who had undergone aortic valve repair and aortic valve sparing root

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WHAT'S NEW?

To the best of our knowledge, this is the largest series of consecutive aortic valve repairs performed in a Polish center, and one of the biggest in the literature. We report the long-term survival as well as freedom from reoperation and from recurrent aortic regurgitation of 504 patients operated over 17 years. The long-term outcome appears favorable even in patients operated for acute aortic dissection.

replacement at the Department of Cardiac Surgery, Upper Silesian Heart Center of the Medical University of Silesia in Katowice, Poland, up to the end of 2019. Patients with coexisting heart disease, requiring additional surgical procedures, and those with acute type A aortic dissection undergoing emergency surgery, were not excluded.

Surgical technique Prior to surgery, transthoracic echocardiography was performed to assess the aortic, mitral, and tricuspid valves, left ventricular ejection fraction, end-diastolic volume, end-systolic volume, the diameters of aortic root, ascending aorta, and left ventricular outflow tract. In patients with an enlarged aorta, computed tomography angiography was additionally performed to accordingly plan the surgery of the aorta.

The El Khoury classification was used to define the type of aortic regurgitation[6] when assigning patients to the aortic valve repair procedure.

The standard surgical access via median sternotomy was used. Cardiopulmonary bypass in normothermic or mildly hypothermic conditions was established between the right atrium and ascending aorta. A vent was placed into the left ventricle through the right superior pulmonary vein for ventricular decompression. One of 3 types of cardioplegic regimens was used (cold blood cardioplegia, miniplegia, and cold del Nido solution) at the surgeon's discretion. In patients with acute type A aortic dissection, cardiopulmonary bypass was established between the right atrium and the brachiocephalic trunk or common carotid artery (via the 8-mm diameter Dacron graft sewn into the artery). Moderate hypothermia (26–28 °C) and temporary brain perfusion with continuous monitoring of cerebral oximetry were used for cerebral protection.

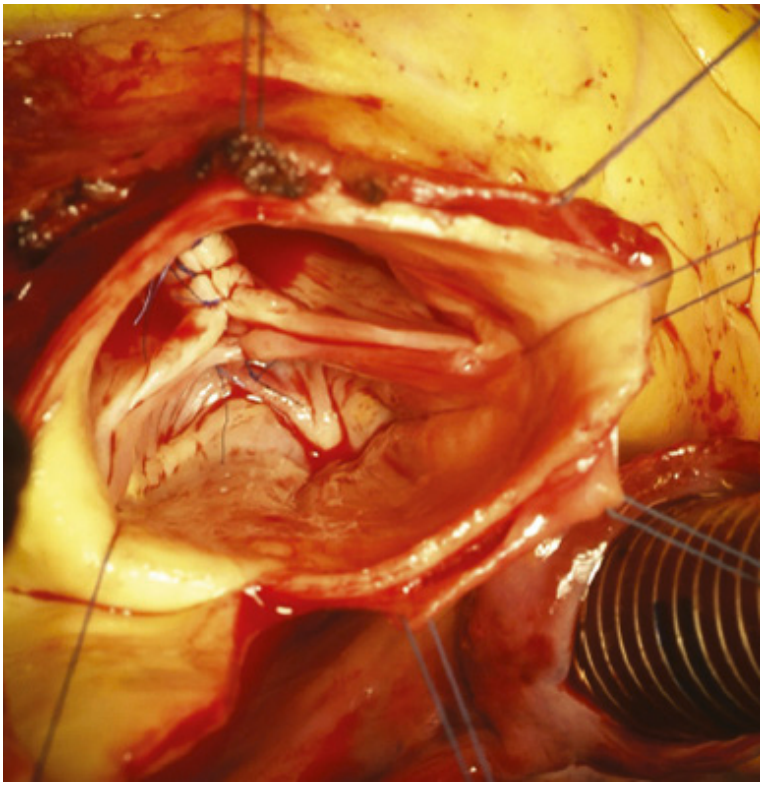

FIGURE 1 Bicuspid aortic valve repair: cusp plication

Following techniques were used for aortic valve repair and aortic annulus stabilization: 1) external stabilization with polytetrafluoroethylene (PTFE) suture[11] or Dacron graft ring (full or semicircular);[12] 2) internal stabilization with Cabrol stitch (subcommissural plication),[13] PTFE suture,[14] or rigid HAART 300 ring (BioStable Science and Engineering, Austin, Texas, United States).[15]

Following techniques were used for aortic valve cusp repair: central plication, free edge plication with the use of PTFE suture, and cusp reconstruction with pericardial patch.[16] In case of a coexisting aortic root aneurysm, the aortic valve sparing operation, either aortic valve reimplantation or aortic root remodeling, was performed. When aneurysm of the ascending aorta or aortic arch was present, it was excised and replaced by the Dacron aortic graft, thus remodeling the sinotubular junction. In some patients, the remodeling of the sinotubular junction was the only indication for the replacement of the ascending aorta.

We assessed mortality, freedom from reoperation, and freedom from at least moderate aortic valve regurgitation.

The mortality and freedom from reoperation status were ascertained from one or more of the following: patients' visit in the outpatient clinic, telephone contact with the patient or patient's relatives, the Polish National Registry of Cardiac Surgical Procedures (Krajowy Rejestr Operacji Kardiochirurgicznych; www.krok.csioz.gov.pl). The KROK registry contains the mortality data obtained from the Polish National Health Fund (Narodowy Fundusz Zdrowia).

The efficacy and durability of aortic valve repair was assessed by echocardiography and aortic valve regurgitation was classified according to a 4-grade scale: (0, none or trivial; 1, mild; 2, moderate; 3, moderately severe; 4, severe).[17]

Mortality, freedom from reoperation, and freedom from aortic valve regurgitation were analyzed in the entire cohort and in 2 subgroups: patients after elective surgery and patients after emergency surgery for acute type A aortic dissection.

Statistical analysis Data are presented as mean (SD) when normally distributed or as median with 25th and 75th percentiles (interquartile range [IQR]) when normality assumptions (the Shapiro-Wilk test) were not met. Categorical data are expressed as a number and percentage.

TABLE 1 Clinical and echocardiographic characteristics of the study patients

Variable		Value
Clinical data (n = 504)		
Male sex		365 (72)
Age, y, median (IQR)		59 (41–68)
NYHA class	I	405 (81)
	II	68 (13)
	III	22 (4.3)
	IV	9 (1.7)
BAV		167 (33)
TAV		337 (67)
Acute aortic dissection		52 (10.3)
Coronary artery disease		70 (13.8)
At least moderate mitral regurgitation		81 (16)
At least moderate tricuspid regurgitation		37 (7.3)
Aortic root aneurysm		132 (26)
Ascending aorta aneurysm		223 (44)
Arterial hypertension		389 (77)
Atrial fibrillation		93 (18)
Diabetes mellitus		62 (12)
Chronic renal failure		19 (3.8)
EUROSCORE II (n = 331), median (IQR)		3.8 (2.5–6.7)
Preoperative echocardiographic data (n = 432)		
Aortic regurgitation grade	0	8 (1.9)
	1	51 (12)
	2	68 (16)
	3	127 (29)
	4	178 (41)
LVOT (n = 217), mm, median (IQR)		24 (20–26)
Aortic annulus (n = 316), mm, median (IQR)		27 (24–29)
Aortic root (n = 367), mm, median (IQR)		42 (37–47)
Ascending aorta (n = 386), mm, median (IQR)		46 (36–52)
EF (n = 371), %, median (IQR)		55 (49–60)
EDV (n = 338), ml, median (IQR)		172 (131–238)
ESV (n = 256), ml, median (IQR)		76 (54–120)

Data are presented as number (percentage) of patients unless otherwise indicated.

Abbreviations: BAV, bicuspid aortic valve; EDV, end diastolic volume; EF, ejection fraction; ESV, end systolic volume; IQR, interquartile range; LVOT, left ventricular outflow tract; NYHA, New York Heart Association; TAV, tricuspid aortic valve

Kaplan–Meier time-to-event curves were generated for the entire cohort and the subgroups were compared with the log-rank (Mantel–Cox) test. The 5- and 10-year survival / freedom from reoperation was estimated and reported with SE.

Association between the 30-day mortality and elective / emergent surgery was assessed with multiple logistic regression. Similarly, this association during follow-up was determined with the univariate Cox proportional hazard ratio analysis.

GraphPad Prism 8.2.0 (GraphPad Software, San Diego, California, United States) was used for all statistical analysis, except the Cox analysis which was done with IBM SPSS Statistics for Windows, version 22 (IBM Corp. Armonk, New York, United States).

The opinion of a local institutional review board was sought. The board decided that the follow-up was not a medical experiment and, therefore, their approval was not required.

RESULTS Between 2002 and 2019, a total of 504 patients underwent aortic valve repair and / or aortic valve sparing root replacement including 452 (89.7%) elective and 52 (10.3%) emergency surgeries for acute type A aortic dissection. The median (IQR) age was 59 (35–66) years, 72.4% were male. The median EUROSCORE II was 3.8 (2.5–6.7). A total of 337 patients (66.9%) had a tricuspid aortic valve and 167 (33.1%), a bicuspid valve (FIGURE 1). Baseline demographic, clinical, and echocardiographic data of the study population are summarized in TABLE 1.

Aortic annulus stabilization procedures performed included external aortic annuloplasty in 57 patients (17.3%) and internal aortic annuloplasty in 217 patients (43%). Additionally, in 260 patients (51.6%), aortic valve cusp repair was performed. Replacement of the aorta was performed in 367 patients (73%). In this group, 137 patients (27%) underwent an aortic valve sparing procedure, including aortic valve reimplantation procedure (David technique) in 67 patients (13.3%) and aortic root remodeling procedure (Yacoub technique) in 70 patients (13.9%). The remaining 230 patients (45.6%) had a segment of the ascending aorta replaced, either because of the enlargement of the ascending aorta or in order to achieve the remodeling of the sinotubular junction. The detailed surgical data are presented in the TABLE 2.

Early postoperative mortality (<30 days after the procedure) was 5.3% (27 patients) and the median (IQR) postoperative hospital stay was 8 days (7–10). The median (IQR) duration of stay at the intensive care unit was 2 (2–3) days. Perioperative complications occurred in

TABLE 2 Surgery scope

Variable		Value
Aortic valve repair		504 (100)
External aortic annuloplasty	Any	57 (11.3)
	PTFE suture	3 (0.6)
	Full ring	9 (1.8)
	Semi ring	45 (8.9)
Internal aortic annuloplasty	Any	217 (43)
	Cabrol stitch (subcomissural annuloplasty)	179 (35.5)
	HAART 300™ ring	18 (3.6)
	PTFE suture	20 (4)
Aortic cusp correction	Any	260 (51.6)
	Central plication	183 (36.3)
	Free edge plication	24 (4.8)
	Pericardial patch reconstruction	7 (1.4)
	Resection	34 (6.7)
	Decalcification	34 (6.7)
	Fenestration closure	2 (0.4)
Aortic valve sparing operation	Any	137 (27)
	Reimplantation (David technique)	67 (13.3)
	Remodeling (Yacoub technique)	70 (13.9)
Ascending aorta replacement with STJ remodeling		230 (45.6)
Aortic arch replacement		26 (5.1)
CABG		59 (11.7)
Mitral valve repair		52 (10.3)
Tricuspid valve repair		18 (3.6)
AF ablation – Maze IV		5 (1)

Data are presented as number (percentage) of patients.

Abbreviations: AF, atrial fibrillation; CABG, coronary artery bypass graft; PTFE, polytetrafluoroethylene; STJ, sinotubular junction

TABLE 3 Surgery data and complications

Parameter	Value
X-clamp, min, median (IQR)	77 (57–103)
CPB, min, median (IQR)	106 (78–156)
Drainage, ml, median (IQR)	700 (500–985)
Ventilation time, h, median (IQR)	13.4 (10.1–20.5)
ICU stay, d, median (IQR)	2 (2–3)
Hospital stay, d, median (IQR)	8 (7–10)
Resternotomy for bleeding	42 (8.3)
Cardiac tamponade	8 (1.6)
Stroke	15 (3)
Renal failure / hemofiltration	21 (4.2) / 12 (2.4)
Pneumonia	12 (2.4)
Wound infection	9 (1.8)
Permanent pacemaker implantation	15 (3)

Data are presented as number (percentage) of patients unless otherwise indicated.

Abbreviations: CPB, cardiopulmonary bypass; ICU, intensive care unit; others, see TABLE 1

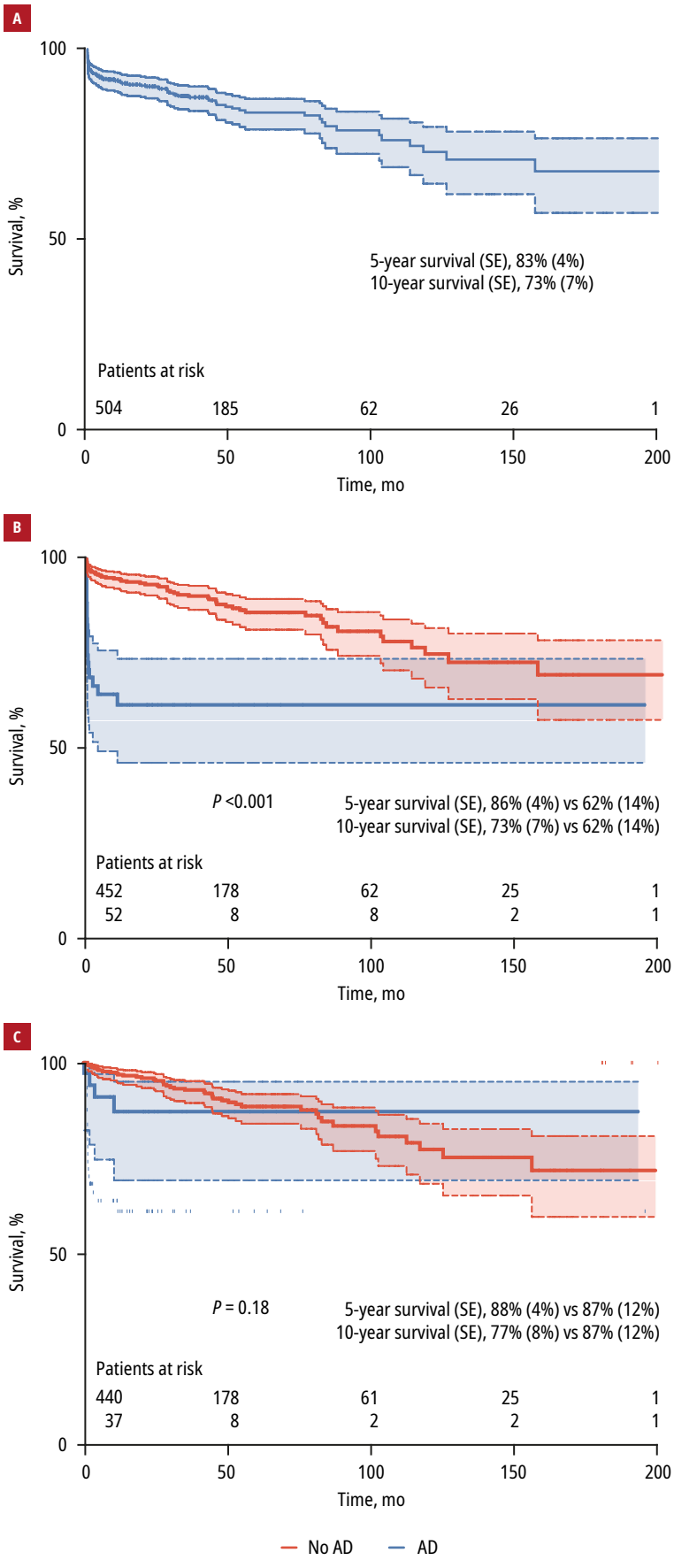

FIGURE 2 Kaplan–Meier survival curves with 95% CI: **A** – all patients; **B** – patients with and without coexisting acute type A aortic dissection (AD); **C** – patients with and without coexisting acute type A aortic dissection who survived early postoperative period (30 days). The subgroups in **B** and **C** were compared with the log-rank (Mantel–Cox) test.

122 patients (24.2%), and the most frequent was postoperative bleeding requiring chest re-exploration in 42 patients (8.3%). Perioperative data are presented in the TABLE 3.

The median follow-up duration was 35.3 (9.2–65.9) months. During the follow-up, 48 patients died, which corresponds with the estimated actuarial 5-year survival (SE) of 83% (4%) and 10-year survival (SE) of 73% (7%) (FIGURE 2A).

In the subgroup of 452 patients who underwent elective surgery 12 (2.6%) early and 44 (10%) late deaths were noted. Estimated actuarial 5-year survival (SE) was 86% (4%) and 10-year survival (SE) was 75% (8%) (FIGURE 2B).

In the cohort of patients who underwent emergency surgery for acute type A aortic dissection, 15 (28.8%) early and 4 (10.8%) late deaths occurred. Actuarial 5-year survival (SE) was 62% (14%), and 10 -year survival was 62% (14%) (FIGURE 2B).

The comparison of both subgroups showed a significantly better survival of patients who underwent elective aortic valve repair than of those after emergency surgery for acute type A aortic dissection (P <0.001, log-rank test; hazard ratio [HR], 5.49; 95% CI, 3.22–9.38; P <0.001) (FIGURE 2B).

The difference in survival was primarily related to early mortality which was much higher in emergency procedures when compared with the elective cases (odds ratio, 14.86, 95% CI, 6.51–34.7; P <0.001). After excluding patients who died during the first 30 postoperative days, the long-term mortality did not differ between the groups (HR, 1.51; 95% CI, 0.47–4.91; P = 0.49) (FIGURE 2C).

During the follow-up, reoperation for the recurrence of aortic valve regurgitation was performed in 24 patients (4.8%) including 22 patients (4.8%) from the elective aortic valve repair group, and 2 patients (3.8%) from the emergency acute type A aortic surgery group. Estimated 5-year freedom from reoperation (SE) was 96% (2%), and 10-year freedom from reoperation was 87% (6%) (FIGURE 3A). The comparison of both subgroups did not reveal significant differences (P = 0.42, log-rank test; HR, 1.49; 95% CI, 0.34–6.55; P = 0.6) (FIGURE 3B).

Follow-up echocardiography was performed in 307 (64.4%) out of 477 patients who survived early postoperative period. The median (IQR) time of follow-up echocardiogram was 26.2 (7.2–52.2) months. Freedom from at least moderate aortic valve regurgitation was confirmed in 266 patients (86.6%). In patients after the elective aortic valve repair and emergent surgery for acute type A aortic dissection, it was 86.8% and 84.2%, respectively (P = 0.98) (FIGURE 4A-4C).

DISCUSSION Reconstructive surgery of the aortic valve can provide a viable alternative for aortic valve replacement only when it yields comparable long-term outcomes.[18] This analysis,

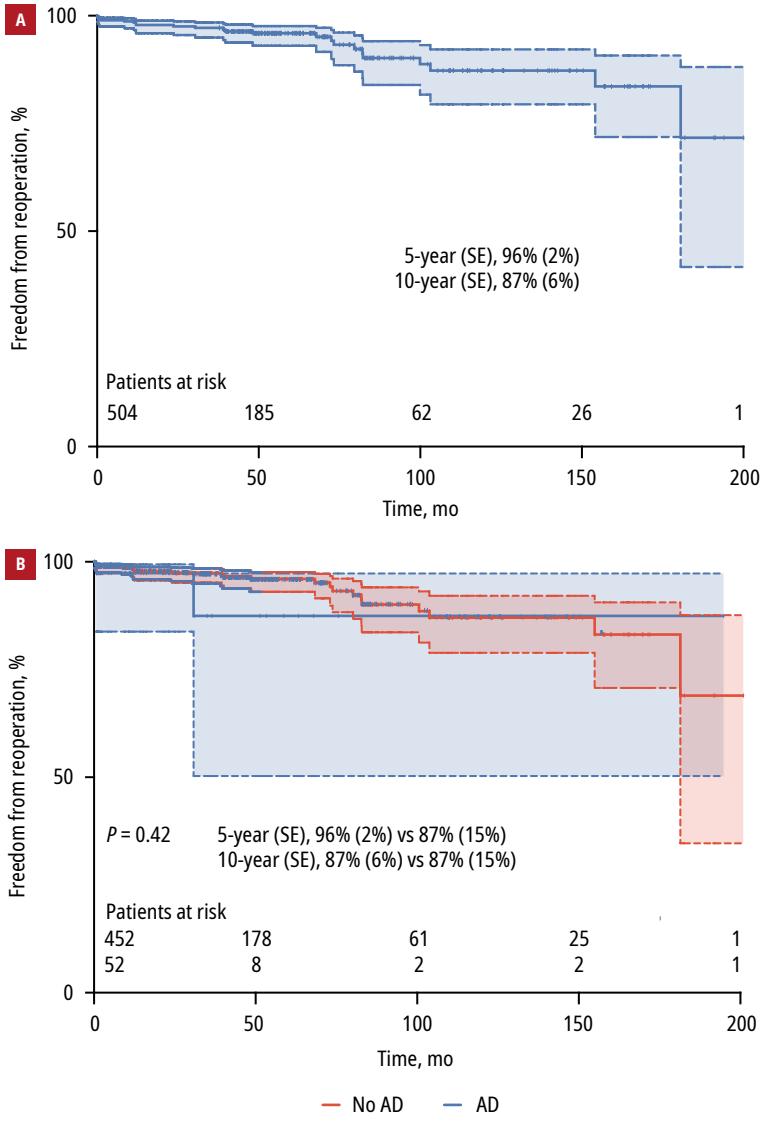

FIGURE 3 Kaplan–Meier freedom from reoperation curves with 95% CI: **A** – all patients; **B** – patients with and without acute type A aortic dissection (AD). The subgroups in **B** were compared with the log-rank (Mantel–Cox) test.

encompassing 17 years of experience in aortic valve reconstructive surgery, shows the evolution of surgical approach to aortic valve repair. First procedures to be performed included simple subcommissural repair (Cabrol stitch) for tricuspid aortic valve and cusp plication for bicuspid aortic valve. Initially, these techniques were used in elective procedures only with the exclusion of emergency surgeries for acute aortic dissection. With growing knowledge on the mechanisms of aortic regurgitation, it has become clear that a more complex approach to aortic valve repair is required to ensure durable repair.[19,20] Based on our growing expertise and data published by David et al[2], El Khoury et al[6], and Aicher et al[4], we started to reconstruct the regurgitant aortic valve at 4 levels: aortic annulus (ventriculo-aortic junction; 65.9% of patients), aortic cusps (51.6%), aortic root (27%) and sinotubular junction (44.2%). Due to this approach we have achieved reasonable standardization and reproducibility of techniques used. Consequently, the outcomes of our aortic valve repairs improved and are comparable to the results reported by others.

El Khoury et al[21] published the outcomes of 475 patients operated within the period of 15 years and report very low early mortality of 0.8% and 10-year survival (SE) of 73% (5%).[21] In our analysis, early mortality was 5.3% and 10-year survival (SE) was 73% (7%). The difference in the early mortality is the result of excluding the emergency surgeries from the El Khoury's group report. After removing these patients from our analysis, early mortality falls to 2.6%.

Zeeshan et al[22] analyzed a large cohort of 1124 patients and reported a 5- and 10-year freedom from reoperation of 93% and 90%, respectively. Our results are similar with 5- and 10-year freedom from reoperation of 96% and 87%, respectively.

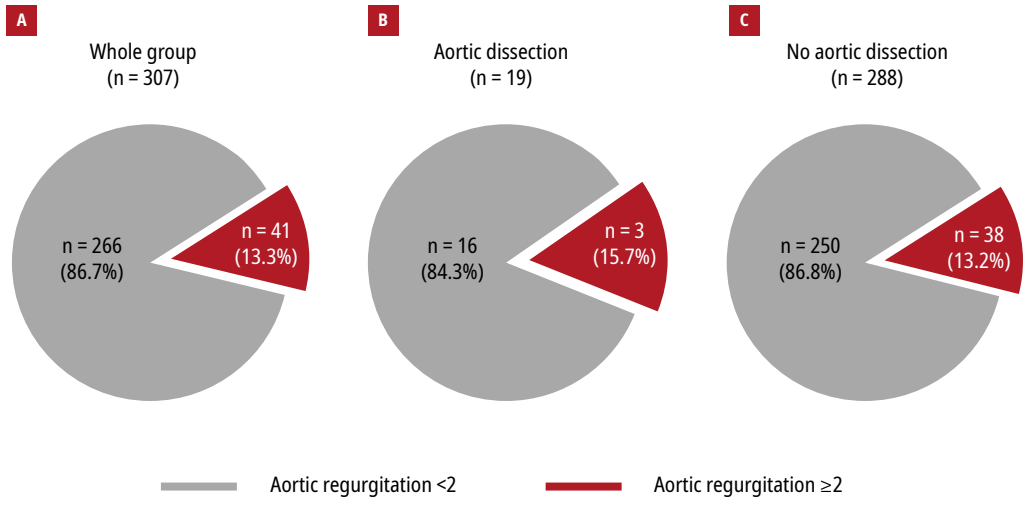

FIGURE 4 Freedom from aortic regurgitation in the whole group (**A**), in those with aortic dissection (**B**), and in those without aortic dissection (**C**)

Of note is the recent trend in surgical aortic valve replacement with biopresthesis being used in an increasing proportion of patients.[23]

The available reports on the durability of bioprostheses show that aortic valve repair with a low ratio of reoperations is an attractive alternative to valve replacement with a bioprosthesis.[24]

Chan et al[25] have reviewed a large cohort of 3152 patients with implanted bioprosthesis and report a 10-year freedom from reoperation (SE) of 78.96% (1.45%). In the subgroup of younger patients (younger than 40 years) the results are even worse with freedom from reoperation (SE) of 50.85% (5.79%). Therefore, it seems that aortic valve repair is an optimal surgical strategy for young patients with aortic valve regurgitation. It allows for longer period of freedom from reoperation in comparison with the replacement with a bioprosthesis. Reconstructive aortic valve surgery also obviates the need for life-long anticoagulation and associated risk of thromboembolic events, which result from aortic valve replacement with a mechanical prosthesis.

Our results prove that aortic valve repair can be performed with low early mortality which compares favorably with the results in a recent large report by Filip et al[23] on isolated aortic valve replacement. Thus, aortic valve repair could be a viable alternative to replacement in selected patients.

An emergency surgery for acute type A aortic dissection does not preclude aortic valve reconstruction; however, in our experience, it is associated with higher early mortality in comparison to elective surgery (28% vs 2.6%). This is attributable to the features of this specific disease with high mortality and usually elevated operative risk.

Of note, David et al[26] in their large analysis encompassing 25 years, identified acute type A aortic dissection as a factor predisposing to higher early mortality in aortic valve reconstructive surgery. Still, in our study, the long-term outcome of those who survived beyond the early postoperative period remains excellent with the survival, freedom from reoperation, and freedom from recurrent aortic regurgitation similar to the elective cases. This encourages us to increasingly use aortic reconstruction techniques as an alternative to the Bentall-de Bono procedure during the surgery for acute type A aortic dissection.

Further standardization of operative techniques and reporting the results will undoubtedly result in a wider adoption of aortic valve repair. The recently launched AVIATOR (Aortic Valve Insufficiency and Ascending Aorta Aneurysm International Registry) may significantly contribute to this standardization and provide a platform for reviewing long-term outcomes.[27]

Limitations This is a retrospective single-center study. The patients were operated on by several surgeons. The decision about the surgical technique was left at the discretion of the operating surgeon. Our results are influenced by the learning curve, therefore, the outcomes of surgery have improved over time. Out of the first 100 operated patients, 16 (16%) required reoperation, whereas out of the subsequent 404 patients, reoperation was performed only in 8 (2%) (P <0.001). During the 17 years, the approach to aortic valve repair has evolved towards more complex surgical techniques, which had a significant impact on the long-term results. Due to the extended follow-up period, not all patients were available for echocardiographic follow-up evaluation.

Conclusions Regurgitant aortic valve repair is a durable and effective surgical procedure associated with low early and late mortality. Aortic valve reconstruction in patients with acute type A aortic dissection yields good long-term results.

ARTICLE INFORMATION

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CONFLICT OF INTEREST None declared.

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REFERENCES

1 Lansac E, de Kerchove L. Aortic valve repair techniques: state of the art. Eur J Cardiothorac Surg. 2018; 53: 1101-1107.

2 David TE, David CM, Feindel CM, Manlhiot C. Reimplantation of the aortic valve at 20 years. J Thorac Cardiovasc Surg. 2017; 153: 232-238.

3 Yacoob MH, Gehle P, Chandrasekaran P, et al. Late results of a valve sparing operation in patients with aneurysm of aorta and root. J Thorac Cardiovasc Surg. 1998; 115: 1080-1090.

4 Aicher D, Langer F, Adam O, et al. Cusp repair in aortic valve reconstruction: does the technique affect stability? J Thorac Cardiovasc Surg. 2007; 134: 1533-1539.

5 Chiappini B, Pouleur AC, El Khoury G, et al. Repair of trileaflet aortic valve prolapse: mid-term outcome in patients with normal aortic root morphology. Interact Cardiovasc Thorac Surg. 2007; 6: 56-59.

6 El Khoury G, Glineur D, Rubay J, et al. Functional classification of aortic root/valve abnormalities and their correlation with etiologies and surgical procedures. Curr Opin Cardiol. 2005; 20: 115-121.

7 Boodhwani M, De Kerchove L, Glineur D, et al. Repair-orientated classification of aortic insufficiency: impact on surgical techniques and clinical outcomes. J Thorac Cardiovasc Surg. 2009; 137: 286-294.

8 Sievers HH, Schmidtke CA. classification system for the bicuspid aortic valve from 304 surgical specimens. J Thorac Cardiovasc Surg. 2007; 133: 1226-1233.

9 Lansac E, Di Centa I, Sleilaty G, et al. Long-term results of external aortic ring annuloplasty for aortic valve repair. Eur J Cardiothorac Surg. 2016; 50: 350-360.

10 Jasinski MJ, Gocol R, Malinowski M, et al. Predictors of early and medium-term outcome of 200 consecutive aortic valve and root repairs. J Thorac Cardiovasc Surg. 2015; 149: 123-129.

11 Schneider U, Aicher D, Miura Y, Schäfers HY. Suture annuloplasty in aortic valve repair. Ann Thorac Surg. 2016; 101: 783-785.

12 Lansac E, Di Centa I, Sleilaty G, et al. Remodeling root repair with an external aortic ring annuloplasty. J Thorac Cardiovasc Surg. 2017; 153: 1033-1042.

13 Cabrol C, Cabrol A, Guiraudon G, et al. Treatment of aortic insufficiency by means of aortic annuloplasty. Arch Mal Coeur Vaiss. 1966; 59: 1305-1312.

14 Schöllhorn J, Rylski B, Beyersdorf F. Aortic valve annuloplasty: new single suture technique. Ann Thorac Surg. 2014; 97: 2211-2213.

15 Gocoł R, Jasiński M, Hudziak D, et al. Surgical correction of aortic regurgitation using a HAART 300™ rigid aortic ring: a novel method to standardize aortic valve repair. Cardiol J. 2019; 26: 799-801.

16 Korniva T. Aortic valve repair update. Gen Thorac Cardiovasc Surg. 2015; 63: 309-319.

17 Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography developed in collaboration with the Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr. 2017; 30: 303-371.

18 Boodhwani M, El Khoury G. Aortic valve repair: indications and outcomes. Curr Cardio Rep. 2014; 16: 490-496.

19 Niwa K. Aortic dilatation in complex congenital heart disease. Cardiovasc Diagn Ther. 2018; 8: 725-738.

20 Zakkar M, Youssefi P, Acar C, et al. Bicuspid aortic valve repair adapted to aortic phenotype. Ann Cardiothorac Surg. 2019; 3: 401-410.

21 Price J, De Kerchove L, El Khoury G, et al. Risk of valve-related events after aortic valve repair. Ann Thorac Surg. 2013; 95: 606-613.

22 Zeeshan, A, Idrees JJ, Johnston DR, et al. Durability of aortic valve cusp repair with and without annular support. Ann Thorac Surg. 2018; 105: 739-748.

23 Filip G, Litwinowicz R, Kapelak, et al. Trends in isolated aortic valve replacement in middle-aged patients over the last 10 years: epidemiology, risk factors, valve pathology, valve types, and outcomes. Kardiol Pol. 2019; 77: 688-695.

24 Bartus K, Litwinowicz R, Bilewska A, et al. Intermediate-term outcomes after aortic valve replacement with a novel RESILIA™ tissue bioprosthesis. J Thorac Dis. 2019; 11: 3039-3046.

25 Chan V, Malas T, Lapierre H, et al. Reoperation of left heart valve bioprostheses according to age at implantation. Circulation. 2011; 124: 75-80.

26 David TE, Feindel CM, David CM, Manlhiot CA. A quarter of a century of experience with aortic valve-sparing operations. J Thorac Cardiovasc Surg. 2014; 148: 872-879.

27 de Heer F, Kluin J, Elkhoury G, et al. AVIATOR: an open international registry to evaluate medical and surgical outcomes of aortic valve insufficiency and ascending aorta aneurysm. J Thorac Cardiovasc Surg. 2019; 157: 2205-2211.