



Research Article

Implementing A Ross Program in A Low-Volume Center: Long-Term Outcomes Compared with Conventional Aortic Valve Replacement

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Abstract

Introduction: The Ross procedure has demonstrated excellent long-term outcomes in young adults requiring Aortic Valve Replacement (AVR), but most data originate from high-volume centers. Whether comparable results can be achieved in lower-volume institutions remains uncertain.

Methods: We conducted a retrospective single-center cohort study of 124 patients younger than 51 years who underwent elective aortic valve surgery between 2003 and 2020. The cohort comprised 43 patients who underwent the Ross procedure and 81 who underwent conventional AVR (mechanical or biological prosthesis). Primary endpoints were in-hospital mortality and morbidity. Secondary endpoints included late survival and valve-related events.

Results: In-hospital mortality was 0% after the Ross procedure versus 2.4% (n = 2) after AVR (p = 0.54). Mean follow-up was 126 ± 66 months (Ross) and 128 ± 60 months (AVR). Late mortality was 9.3% in the Ross group (all non-cardiac-related deaths) versus 15.2% in the AVR group (primarily cardiac or valve-related causes). At 15 years, overall survival was 83.9% (Ross) versus 74.4% (AVR) (p = 0.54). Freedom from death and valve-related complications favored the Ross procedure (p = 0.054). After adjustment for age, dyslipidemia, left ventricular ejection fraction, and body mass index ≥30 kg/m², the Ross procedure independently predicted improved late survival and reduced valve-related morbidity (p = 0.041).

Conclusion: In a structured program led by an experienced surgeon, the Ross procedure can be safely implemented in a low-volume center and is associated with excellent early outcomes and favorable long-term event-free survival compared with conventional AVR in selected young adults.

Keywords: Aortic Valve Replacement; Long-Term Outcomes; Low-Volume Center; Ross Procedure; Valve-Related Complications

Introduction

Aortic valve disease in young and middle-aged adults presents a distinct clinical challenge due to prolonged cumulative lifetime risk of prosthesis-related morbidity and mortality. Identifying the optimal valve substitute in this population is therefore of paramount importance. Two principal options are currently available for Aortic Valve Replacement (AVR): conventional prosthetic valve implantation (mechanical or biological) and the Ross procedure using a pulmonary autograft replacement. Despite increased technical complexity and longer operative time, the Ross procedure has demonstrated superior long-term outcomes compared with conventional AVR in appropriately selected patients. Multiple observational studies and meta-analyses report improved freedom from valve-related complications and long-term survival comparable to age- and sex-matched general population [1-5]. These findings have contributed to a renewed interest in re-evaluating clinical guidelines on valve selection for younger adults requiring AVR [6]. However, evidence originates from high-volume, specialized centers with extensive Ross experience [7]. Generalizability to low-volume institutions remains uncertain. The aim of this study was to assess the feasibility and outcomes of a Ross program implemented in a single low-volume center.

Methods

Ethical Considerations

This retrospective, single-center, observational cohort study was

approved by the institutional ethics committee (Ethics Committee 71, approval number B2024CE.12, dated March 14, 2024), and authorization was obtained from the French Data Protection Authority. Data collection and storage were centrally managed by the hospital’s Department of Research and Innovation to ensure confidentiality and data integrity. Informed consent was obtained from all participants for anonymized data analysis and publication.

Study Design and Population

The study included all patients younger than 51 years who underwent aortic valve replacement at our institution between January 2003 and December 2020. Of 10,536 cardiac surgical procedures performed, 4,449 involved aortic valve surgery. Patients with acute aortic dissection, active endocarditis, emergency surgery, or concomitant procedures (mitral/tricuspid valve surgery or coronary artery bypass grafting) were excluded. The final study cohort comprised 124 patients (Table 1): 43 patients underwent the Ross procedure (Ross group), and 81 patients underwent conventional aortic valve replacement (AVR group). Baseline pathology differed slightly between groups. Isolated aortic stenosis was present in 28.4% of AVR patients and 37.2% of Ross patients (p = 0.295), isolated aortic regurgitation in 38.3% versus 16.3% (p=0.006), and mixed disease in 33.3% versus 46.5% (p=0.161). A bicuspid or monocuspid valve was more frequent in the Ross group (93% vs 70.4%, p=0.02). Ascending aortic aneurysm (≥ 45 mm) was observed in 36.4% (n = 16) of Ross patients and 37% (n =30) of AVR patients. Patient selection for the Ross procedure was based on surgeon assessment, typically involving physically active, non-obese individuals with preserved cardiac and respiratory function. For patients unsuitable for Ross, valve type was chosen in accordance with guideline recommendations [8].

Patient’s characteristics	AVR group	Ross group	p value
	(n = 81)	(n = 43)	
Patient-related factors			
Age (years) mean ± σ [range]	42.2 ± 6.3 [24;50]	39.4 ± 7.5[21;50]	0.04
Biological sex n male (%)	63 (77.8)	36 (83.7)	0.552
Chronic lung disease ^a n (%)	7 (8.6)	1 (2.3)	0.26
Extracardiac arteriopathy ^b n (%)	2 (2.4)	1 (2.3)	0.724
Poor mobility ^c n (%)	1 (1.2)	1 (2.3)	1
Previous cardiac surgery n (%)	4 (4.9)	2 (4.6)	1
Active endocarditis ^d n (%)	1 (1.2)	2 (4.6)	1
Critical preoperative state ^e n (%)	0	0	
Creatinine clearance > 85 ml/min n (%)	80 (98.8)	42 (97.7)	1

Creatinine clearance 50–85 ml/min n (%)	1 (1.2)	1 (2.3)	1
Diabetes on insulin n (%)	1 (1.2)	0	1
History of cancer n (%)	2 (2.4)	0	0.54
History of stroke n (%)	3 (3.7)	1 (2.3)	1
Current smoking n (%)	24 (28.9)	17 (39)	0.264
Hypercholesterolemia n (%)	8 (9.6)	10 (23.3)	0.044
BMI $\geq$ 30 Kg/m ² n (%)	21 (25.9)	2 (4.6)	0.032
Cardiac-related factors			
Arterial hypertension n (%)	23 (28.4)	6 (14.0)	0.071
CCS angina class 4 n (%)	1 (1.2)	0	1
Recent MI < 90 days n (%)	0	1 (2.3)	0.347
History of myocardial infarction n (%)	1 (1.2)	2 (4.6)	0.276
LVEF (%) mean $\pm$ σ	57.3 $\pm$ 8.8	62.6 $\pm$ 9.4	< 0.01
LVEF > 50% n (%)	64 (79.0)	41 (95.4)	
LVEF 31–50% n (%)	17 (21.0)	2 (4.6)	0.026
Atrial fibrillation n (%)	3 (3.7)	0	0.551
Pulmonary hypertension 31–55 mmHg n (%)	4 (4.9)	1 (2.3)	0.658
Pulmonary hypertension > 55 mmHg n (%)	0	0	
NYHA class I n (%)	10 (12.3)	5 (11.6)	
NYHA class II n (%)	61 (75.3)	32 (74.4)	1
NYHA class III n (%)	9 (11.1)	6 (13.9)	
NYHA class IV n (%)	1 (1.2)	0	
Operation-related factors			
Surgery on thoracic aorta n (%)	31 (38.3)	43 (100)	
Elective operation n (%)	79 (97.5)	41 (95.3)	1
Urgent operation ^f n (%)	2 (2.4)	2 (4.6)	
Single non-CABG procedure n (%)	50 (61.7)	0	
Double procedure n (%)	0		
Triple procedure n (%)	31 (38.3)	43 (100)	
Euroscore II (%) mean $\pm$ σ [95% CI]	2 $\pm$ 1.8 [1.6–2.4]	3.5 $\pm$ 1.7 [3–4]	< 0.001

σ : standard deviation.. ^{a,b,c,d,e,f} definitions of Euroscore II. BMI: body mass index. CCS: Canadian Cardiovascular Society. MI: myocardial infarction. LVEF: left ventricular ejection fraction. NYHA: New-York Heart Association. CABG: coronary artery bypass graft. CI: confidence interval.

Table 1: Patient's Characteristics.

Surgical Technique

All Ross procedures were performed by a single senior surgeon, who also carried out 87% of Bentall procedures and 30% of isolated AVRs during the study period. Before initiating the Ross program, the surgeon had received specific training in pulmonary autograft harvesting and completed the first case under the supervision of an experienced Ross operator. He was already accustomed to managing prolonged cross-clamp and bypass times through complex coronary reconstructions using the internal thoracic artery [9]. Over the study period, this surgeon performed 213 Bentall procedures, 91 valve-sparing root replacements, and 53 Ross procedures. The Ross operation was performed using a full root replacement technique [10]. Initial 9 procedures were performed without external reinforcement; subsequently, 34 patients received autograft inclusion within a polyester vascular graft (Vascutek Gelweave Valsalva). Right ventricular outflow tract reconstruction was achieved with a stentless bioprosthesis (Medtronic® Freestyle, 29 mm) in all cases. In the AVR group, biological prostheses (Edwards® Perimount/Magna) were implanted in 13% (n = 10) and mechanical prostheses (Saint Jude Medical® Regent/Master) in 87% (n = 70). A Bentall procedure was performed in 38% (n = 30) of AVR patients. Cardiopulmonary bypass was conducted under normothermic conditions, with optimization based on venous oxygen saturation, mean arterial pressure, hematocrit, pH, and lactate levels. Myocardial protection was achieved with continuous retrograde blood cardioplegia: tepid (25°C) for Ross and Bentall procedures, and warm for isolated AVR.

Follow-Up And Outcomes

All patients were followed annually by their referring cardiologist. Follow-up data were collected between March 2024 and July 2024 through multiple sources: the institutional electronic health records (Brest University Hospital database), a dedicated outpatient consultation with a member of the cardiac surgical team, the last echocardiography, and, in cases of incomplete clinical follow-up, the French national mortality registry (INSEE database). The primary outcome was the occurrence of major in-hospital complications within 30 days or during prolonged hospitalization, as defined by the EPICARD registry [11]. Secondary outcomes

included long-term overall survival and valve-related events. Cause of death was determined from medical records and classified as cardiac or non-cardiac. All sudden, unexplained, or unknown-cause deaths were categorized as cardiac. Valve-related events were defined as reintervention on the aortic or pulmonary valve, thromboembolic events (stroke, transient ischemic attack, myocardial infarction, or peripheral embolism), prosthetic valve endocarditis, valve thrombosis, and major bleeding event (bleeding causing death, stroke, or requiring hospitalization).

Statistical Analysis

Continuous variables are presented as mean $\pm$ standard deviation, and categorical variables as counts and percentages. Group comparisons were performed using the Student's t-test or Mann–Whitney U test for continuous variables, and the Chi-square or Fisher's exact test for categorical variables. Univariate analysis was conducted to identify predictors of late mortality in the AVR group. Variables with $p < 0.10$ were entered into a multivariable Cox proportional hazards model to determine independent predictors. The effect of surgical strategy (Ross vs AVR) on overall and event-free survival was assessed using Kaplan–Meier curves with log-rank testing, and adjusted using a Cox model with stepwise variable selection (Wald forward and backward methods). Analyses were performed with IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA). A two-sided $p < 0.05$ was considered statistically significant.

Results

In-Hospital Outcomes

Operative times were longer in the Ross group compared to the AVR group. Mean aortic cross-clamp time and cardiopulmonary bypass time were 251 ± 35 minutes and 302 ± 66 minutes in the Ross group versus 101 ± 30 minutes and 139 ± 67 minutes in the AVR group ($p < 0.001$ for both comparisons). In-hospital mortality was 0% in the Ross group and 2.4% (2 patients) in the AVR group ($p = 0.54$). Observed in-hospital mortality did not significantly differ from predicted mortality as calculated by the EuroSCORE II in either group (Table 1). In-hospital morbidity is detailed in (Table 2).

	AVR group (n = 81)	Ross group (n = 43)	p value
Post-operative bleeding* n (%)	1 (1.2)	1 (2.3)	1
Late tamponnade* n (%)	2 (2.5)	1 (2.3)	1
Sterno-mediastinitis* n (%)	1 (1.2)	0	1
Low cardiac output ^a n (%)	2 (2.5)	0	0.54
Peri-operative infarction ^b n (%)	1 (1.2)	0	1
Post-op CPBIA, ECMO-ECLS ^c n (%)	0	0	1
Cardiac arrest [†] n (%)	1 (1.2)	0	1
Renal failure requiring dialysis n (%)	0	1 (2.3)	0.352
Prolonged ventilation > 24 h n (%)	1 (1.2)	4 (9.3)	0.052
Re-intubation n (%)	1 (1.2)	1 (2.3)	1
Lung infection / pneumonia n (%)	5 (6.2)	10 (23.3)	0.009
Digestive hemorrhage n (%)	0	0	1
Mesenteric infarction n (%)	0	0	1
Permanent stroke n (%)	2 (2.5)	0	0.54
Transient stroke n (%)	0	2 (4.6)	1
Coma > 24 h n (%)	0	0	1
Atrial fibrillation ^d n (%)	8 (9.9)	6 (13.9)	0.51
Definitive pacemaker n (%)	3 (3.7)	0	0.551
Multi-organ failure [†] n (%)	1 (1.2)	0	1
Transfusion n (%)	35 (43.2)	19 (44.2)	1

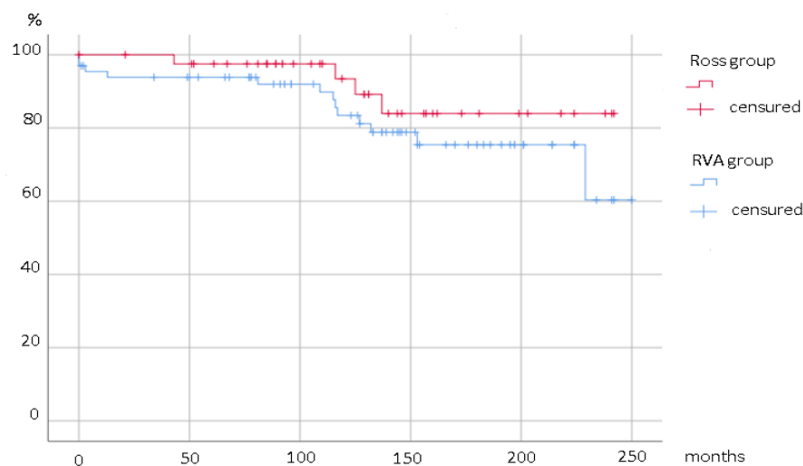
* Patient's condition requiring a reintervention; ^a Inotropic support > 24 hours; ^b Peri-operative infarction requiring therapeutic management (inotropes, circulatory support, etc.); ^c Difficult CPB withdrawal or ICU cardiac failure; ^d With treatment at discharge; [†] Cause of in-hospital death.

Table 2: In-Hospital Morbidity.

Survival

The mean follow-up was 126 ± 66 months for the Ross group and 128 ± 60 months for the AVR group. Late mortality occurred in 9.3% (n = 4) of Ross patients and 15.2% (n = 12) of AVR patients. All deaths in the Ross group were non-cardiac (road traffic accident, brain tumor, liver cirrhosis, and suicide). No aortic regurgitation or pulmonary valve degeneration was observed in Ross patients who

died during follow-up. In contrast, 10 of the 12 deaths in the AVR group were due to cardiac causes (1 prosthetic valve endocarditis, 2 intracerebral hemorrhages, 1 prosthetic valve thrombosis, and 6 deaths of unknown cause). The remaining two deaths were cancer-related. The long term survival in the Ross group was 97.5% at 5 years, 93.1% at 10 years, and 83.9% at 15 years, not different (p = 0.54) than the long term survival in the AVR group, respectively 93.5%, 82.8%, 10, and 74.4% (Figure 1).



Patients at risk	50	100	150	200
Ross 43	36	25	10	4
RVA 81	55	41	20	10

Figure 1: Late survival.

Valve Related Events

Loss to follow-up occurred in 12.7% (10 patients) of AVR patients (all mechanical valve) and 2.3% (1 patient) of Ross patients. In the Ross group, 5 reinterventions (12.2%) were required: 1 endocarditis managed with Bentall procedure 1 autograft dilatation requiring David procedure, 1 supra-avalvular pulmonary stenosis requiring surgical pulmonary valve replacement, 1 external compression of the pulmonary bioprosthesis managed with off-pump pericardiectomy, and 1 early pulmonary bioprosthesis degeneration managed with percutaneous pulmonary valve replacement. In the AVR group, 10 reinterventions (14.9%) were performed: structural bioprosthetic degeneration (n = 4), mechanical valve thrombosis (n=1), and prosthetic valve endocarditis (n 5). No in-hospital mortality occurred following reintervention in either group. In the AVR group (67 patients with complete follow-up), non-fatal valve-related complications included 5 thromboembolic events

(7.4%), 7 major bleedings (13.4%), and 4 endocarditis (6%). In the Ross group (41 patients with complete follow-up), there were no thromboembolic events, no major bleeding events, and 1 endocarditis (2.4%).

Freedom from Events

Nine patients (21.9%) in the Ross group experienced 10 composite events (non-fatal valve-related complications or death) compared to 30 patients (43.5%) experiencing 38 events in the AVR group. Freedom from all-cause mortality and non-fatal valve-related complications (Figure 2) was higher in the Ross group, approaching statistical significance (p = 0.054). After multivariable adjustment for baseline differences in age, dyslipidemia, left ventricular ejection fraction, and body mass index ≥ 30 kg/m², the Ross procedure emerged as an independent protective factor against late mortality and valve-related complications (p = 0.041).

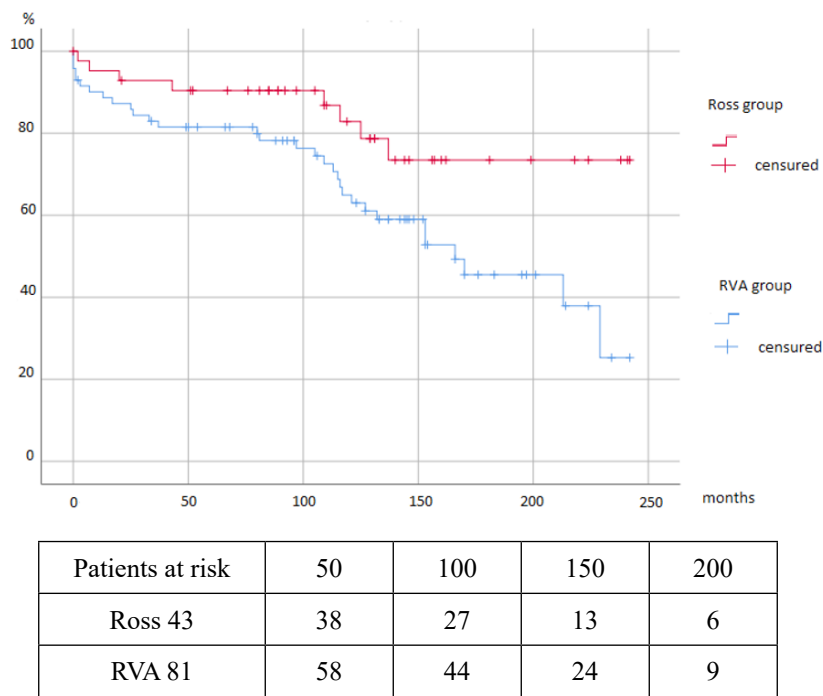


Figure 2: Late survival freedom from mortality and valve related complications.

Valve Dysfunction at Last Echocardiography

In the AVR group (n=67), valve dysfunction was documented in 3 patients (4.5%): 1 structural aortic bioprosthesis degeneration (mean gradient >35 mm Hg), and 2 mechanical valve entrapment by pannus. In the Ross group (n=41), valve dysfunction was documented in 4 patients (9.8%): 2 aortic regurgitation greater than grade 2, and 2 structural pulmonary bioprosthesis degeneration (mean gradient >25 mm Hg).

Risk Factor Analysis for Late Mortality

Univariate analysis did not identify any significant independent predictors of late mortality in the AVR group (Table 3), including age, sex, comorbidities, or preoperative left ventricular function. Notably, all AVR patients with preoperative left ventricular ejection fraction ≤ 50% demonstrated normalization > 50% on final echocardiography.

Patient’s characteristics (n = 79)	Alive patients (n = 67)	Dead patients (n = 12)	p value
Age (years) mean ± σ	41.8 ± 6.6	44.3 ± 4.9	0.2
Female n (%)	14 (20.9)	4 (33.3)	0.34
Chronic lung disease ^a n (%)	5 (7.5)	1 (8.3)	0.91
Extracardiac arteriopathy ^b n (%)	2 (3.0)	0	0.54
Previous cardiac surgery n (%)	6 (8.9)	1 (16.6)	0.41
Active endocarditis ^c n (%)	1 (1.5)	0	0.67
Creatinine clearance < 85 ml/min n (%)	1 (1.5)	0	0.67
Diabetes on insulin n (%)	1 (1.5)	0	0.67
CCS angina class 4 n (%)	1 (1.5)	0	0.67

NYHA mean $\pm$ σ	2.1 $\pm$ 0.7	2.0 $\pm$ 0.5	0.65
LVEF (%) mean $\pm$ σ	58.00 $\pm$ 8.3	55.5 $\pm$ 10.4	0.38
LVEF < 50% n (%)	13 (25.4)	4 (16.6)	0.29
Pulmonary hypertension 31–55 mmHg n (%)	3 (4.5)	1 (8.3)	0.57
Urgent operation ^d n (%)	2 (3.0)	0	0.54
Euroscore II (%) mean $\pm$ σ	1.97 $\pm$ 1.88	2.01 $\pm$ 1.09	1
Mechanical valve n (%)	56 (83.6)	12 (100)	0.68
Bentall n (%)	27 (40.3)	5 (41.7)	1
BMI mean $\pm$ σ	26.1 $\pm$ 5.1	26.7 $\pm$ 4.7	0.73
Arterial hypertension n (%)	21 (31.3)	1 (8.3)	0.1
Dyslipidemia n (%)	8 (11.9)	0	0.2
Current smoking n (%)	21 (31.3)	3 (25)	0.66
Atrial fibrillation n (%)	1 (1.5)	1 (8.3)	0.16

σ : standard deviation. a,b,c,d definitions of EuroSCORE II. CCS: Canadian Cardiovascular Society. MI: myocardial infarction. NYHA: New York Heart Association. LVEF: left ventricular ejection fraction. BMI: body mass index.

Table 3: Risk Factors of Late Death in the AVR Group.

Discussion

The validation of our Ross program relied on comparing in-hospital and long-term outcomes with those previously reported for conventional AVR. Our findings demonstrate that, when performed by an experienced surgeon, the Ross procedure can be safely implemented in a low-volume center, achieving excellent early and long-term results in carefully selected young and middle-aged adults.

To limit confounding, we excluded patients requiring emergency surgery or concomitant cardiac procedures. Bentall operations were classified within the AVR group, as aortic root dilatation was present in 36% of Ross patients, who otherwise would have required a Bentall procedure. Given the limited number of Ross cases, case matching was not feasible; instead, baseline differences, particularly age, body mass index ≥ 30 kg/m², dyslipidemia, and preoperative ejection fraction, were addressed through univariate and multivariable modeling. None of these factors was independently associated with late mortality in the AVR cohort. Although baseline variables differed between groups, none was independently associated with late mortality in the AVR cohort (Table 3). Patients requiring concomitant procedures such as mitral or tricuspid surgery or coronary bypass were excluded. The higher EuroSCORE II observed in the Ross group reflected the composite

nature of the operation, involving three valve components, whereas most AVR cases were isolated procedures. Patients selected for the Ross procedure were generally healthier, reflecting surgeon preference for offering this time-consuming intervention to individuals with fewer comorbidities. For long-term assessment, we analyzed only the most recent echocardiography to evaluate actuarial survival free from valve-related complications. This approach accounted for the progressive nature of structural valve degeneration in both bioprostheses and pulmonary autografts, as well as the potential for late aortic regurgitation after Ross.

Prior studies have shown superior long-term survival with the Ross procedure compared with mechanical or bioprosthetic AVR in selected young adults [4,5,12-14]. Meta-analyses suggest that this benefit is greatest when perioperative mortality remains below 2.5% [15-17]. In our cohort, early mortality after Ross was zero, despite higher predicted operative risk by EuroSCORE II, reflecting careful patient selection and optimized perioperative management with normothermic bypass and continuous retrograde blood cardioplegia [18]. Longer operative times, however, were associated with more respiratory complications, particularly in smokers and patients with elevated body mass index; in our practice, BMI ≥ 30 kg/m² is a contraindication to the Ross procedure. The overall rate of reintervention did not differ significantly between groups. In the Ross cohort, most reoperations were related to early

technical issues during the learning curve, including anastomotic stenosis and implantation without conduit reinforcement. Right ventricular outflow tract reconstruction with a stentless bioprosthesis (Medtronic® Freestyle) provided satisfactory mid-term results, although one case of early degeneration occurred. While homografts are traditionally preferred, current evidence does not demonstrate clear superiority over stentless xenografts [19,20].

Importantly, none of the late deaths in the Ross group was cardiac or valve-related. In the AVR group, outcomes were consistent with published standards, yet most late deaths were attributable to valve-related complications. This finding underscores the long-term limitations of conventional AVR in young patients, particularly those with mechanical valves requiring lifelong anticoagulation [20,21]. The cumulative impact of cardiovascular risk factors such as age, obesity, hyperlipidemia, hypertension, and smoking likely contributed to poorer outcomes, although their uneven distribution between groups complicates interpretation.

Although the Ross procedure is often perceived as complex and resource-intensive, our findings indicate that it can be safely implemented outside high-volume centers when performed by surgeons with advanced expertise in aortic root and valve-sparing procedures. While surgical case volume is an important determinant of outcomes, several studies suggest that individual surgeon experience may be more predictive than institutional volume alone [22,23]. The Ross procedure effectively transforms a single-valve operation into a double-valve operation, thereby increasing overall complexity. Both surgeon and anesthesiologist must be proficient in managing prolonged cross-clamp and bypass times. To optimize outcomes, a structured Ross program should include strong expertise in complex aortic surgery, formal training at an established Ross center, and mentorship by an experienced Ross operator during the initial cases.

This study has several limitations. Its retrospective, single-center design introduces inherent biases, and the sample size limited the power to detect some differences, particularly after adjustment. Only one senior surgeon performed the Ross procedures, while all AVR cases were distributed among several surgeons, which may have influenced outcomes. Baseline characteristics also differed significantly between groups, reflecting selection bias. Furthermore, patients lost to follow-up in the AVR group were considered event-free, potentially underestimating the true incidence of late mortality and valve-related complications (Figure 2). Finally, the study was not designed to demonstrate superiority of the Ross procedure over AVR, as this advantage has already been established in prior literature.

Conclusion

Rather than reserving the Ross procedure exclusively for high-volume centers, our results suggest appropriately selected candidates at lower-volume centers can achieve comparable results provided several conditions are met: (1) individual surgeon expertise and commitment, (2) formal training in an established Ross center, (3) mentorship by experienced Ross operators during initial cases, (4) access to optimized cardiopulmonary bypass and myocardial protection, and (5) rigorous patient selection criteria.

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