Aortic Root Replacement with Reimplantation of the Aortic Valve: A Low-Volume Center Experience

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Abstract

Background Most data after root replacement with reimplantation of the aortic valve originate from high-volume centers. This raises concerns about the generalizability of these data and the reproducibility of this complex procedure. Aim of this study is to assess the perioperative and midterm outcomes of this procedure in a low-volume center.

Methods We performed a retrospective analysis of the data of 72 patients, who underwent root replacement with reimplantation of the aortic valve in a single center between 2011 and 2020. Time to event analysis was performed with Kaplan–Meier curves. Longitudinal analysis of serial echocardiographic data was performed with a mixed-effects ordinal logistic regression model.

Results In-hospital mortality was 1.4%, with absence of any neurological events during the perioperative period. At midterm follow-up, two further patients died. Overall survival rates at 1 and 5 years were 98.5% (95% confidence interval [CI]: 97–100%) and 96.3% (95% CI: 93.8–98.8%), respectively. During follow-up, five patients (6.9%) required reoperation on the aortic valve. The incidence of moderate and severe aortic regurgitation at 5 years was 6.6% (95% CI: 2.4–13.6%) and 0.6% (95% CI: 0.1–3.2%), respectively. Mild aortic regurgitation at hospital discharge ($p < 0.001$) and cusp plication ($p = 0.0121$) were associated with a higher incidence of moderate or severe aortic regurgitation at follow-up.

Conclusion Reimplantation of the aortic valve is safe and feasible even in a low-volume center. Mortality, freedom from reoperation, and incidence of moderate or severe aortic regurgitation at follow-up are comparable to those of high-volume centers.

Keywords
- aortic valve and root
- aorta/aortic
- outcomes (includes mortality, morbidity)

Introduction

Aortic root replacement with reimplantation of the aortic valve has been first described almost 30 years ago and is an established technique for the treatment of patients with root aneurysm and normal or near-normal aortic cusps.[1] Technical complexity of the procedure and skill and experience of the surgeon are some of the factors associated with the low uptake of this technique from the surgical community, with the procedure being performed on only 14% of patients undergoing root surgery in the United States.[2] Restoration

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of the aortic valve geometry with normal aortic valve function is based on precise and meticulous surgical technique and is of great importance for the success of the operation.[3] Although proven safe and effective, some centers have shown a considerable incidence of residual or progressive aortic regurgitation postoperatively, raising concerns about the reproducibility and the long-term outcomes of this technique.[4–7] Moreover most of the published data originate from high-volume centers further questioning the generalizability of their results and the reproducibility of this complex procedure in low-volume centers.

Aim of this study is to evaluate the early and midterm postoperative outcomes of patients undergoing root replacement with reimplantation of the aortic valve and gain more information about the reproducibility of this complex procedure in a low-volume center.

Patients and Methods

We performed a retrospective analysis of the data of 72 consecutive patients who underwent root replacement with reimplantation of the aortic valve in a single center from May 2011 to January 2020. The study was approved and individual informed consent was waived by the local ethics committee (BASEC-Number. 2020–00496).

Surgical Technique

In all cases, a tubular straight Dacron graft (Gelweave, Terumo Aortic, Vascutek Ltd., Inchinnan, UK or FlowWeave, Jotec, Hechingen, Germany) was used. All procedures were performed over a median sternotomy by six surgeons. Aortic neosinuses were created in 48 patients (66.7%), through plication of the Dacron graft with one stich at the base and one at the height of each commissure using 4–0 braided polyester sutures. Additionally, anatomic diameter reduction of the sinotubular junction was achieved through resuspension of the aortic valve above the commissures with wider bites at the Dacron prosthesis. After resection of the ascending aorta and the aortic sinuses, sizing of the aortic valve annulus was performed with the use of Hegar dilators or accurate aortic root sizers (sizers of Freestyle aortic root bioprosthesis, Medtronic, Minneapolis, Minnesota, United States). Dacron graft plication for neosinus creation causes a reduction in the proximal diameter of the Dacron graft. Therefore, Dacron graft size selection was based on the decision to create aortic neosinuses or not. Accordingly, the Dacron graft diameter size was 5 mm larger than the measured aortic valve annulus size in cases of neosinus creation or 2 mm larger than the measured aortic valve annulus size when no neosinuses were created. The oversized Dacron grafts used for neosinus creation were then plicated appropriately, so that their proximal diameter after plication was 2 mm larger than the measured diameter of the native aortic valve annulus. Before implantation, the diameter of the plicated Dacron grafts was measured with the same sizing tools used for sizing the aortic valve annulus to control for mismatching. In all cases, the Dacron grafts were implanted on the aortic annulus with 2–0 braided polyester sutures tied down over a Hegar dilator placed into the left ventricular outflow tract to avoid unintended annular size reduction. The aortic valve was reimplanted on the Dacron graft with three running 5–0 monofilament polypropylene sutures, one for each cusp. The coronary buttons were reimplanted using a running 5–0 monofilament polypropylene suture. The anastomosis between the Dacron graft and the remaining aorta was performed with a running 4–0 monofilament polypropylene, Teflon felt-supported suture.

Cardiopulmonary bypass was established with arterial cannulation of the right subclavian artery in patients undergoing concomitant hemiarch replacement. In all other cases, the distal ascending aorta was used for arterial cannulation. Venous cannulation of the right atrium was performed in all but four cases of patent foramen ovale (PFO) closure, one mitral valve repair and one left atrial myxoma resection, where a bicaval cannulation was used. Patients were cooled to 32°C in isolated aortic root procedures. Hemiarch replacement was performed under moderate hypothermic circulatory arrest (30–32°C) and antegrade cerebral perfusion over the right subclavian artery. Bretschneider solution was used for myocardial protection and applied antegrade and directly to the coronary ostia. In cases of coronary artery bypass surgery, cardioplegia was additionally administered over the bypass grafts.

Data Collection and Follow-up

The preoperative and operative data of the patients are presented in ►**Tables 1** and **2**, respectively. The aortic valve function was assessed at 3 months, 1 year, and annually thereafter by transthoracic echocardiography. Follow-up was closed on March 31, 2020, for this report. The median echocardiographic follow-up time was 1.8 years, extending from 0 to 8.3 years. The quantification of the completeness of follow-up was based on the ratio of the total observed person-time and the potential person-time of follow-up, as proposed by Clark et al.[8] Accordingly, the completeness of follow-up was 73.1%. Only one person was lost to follow-up, a tourist undergoing emergency surgery for acute type-A aortic dissection and returning to his home country after hospital discharge.

Data Analysis

The statistical analyses were performed with SPSS version 24 (IBM, Armonk, New York, United States) and R version 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria). Categorical variables are presented as counts (percentages) and continuous variables as mean ± standard deviation by normally distributed data and median (1st–3rd quartile) by non-normally distributed data. Assessment of the normality of data distribution was performed using the Shapiro–Wilk test and histogram inspection. Continuous data were compared with the *t*-test or the Mann–Whitney *U*-test according to the normality of data distribution. Categorical data were compared with the Chi-squared or the Fisher's exact test

Table 1 Preoperative data

Demographic	*n* (%)/ mean ± SD
No. of patients	72 (100)
Mean age ± SD (y)	56.4 ± 11.2
Range	22–76
Male gender	67 (93.1)
Associated diseases	
Marfan syndrome	2 (2.8)
Diabetes mellitus	8 (11.1)
Arterial hypertension	51 (70.8)
Dyslipidemia	35 (48.6)
Previous pulmonary disease	2 (2.8)
Previous stroke	4 (5.6)
Peripheral vascular disease	2 (2.8)
Renal failure on hemodialysis	0
Urgent/emergency surgery	11 (15.3)
Previous cardiac surgery	2 (2.8)
Atrial fibrillation	1 (1.4)
Left ventricular ejection fraction <40%	3 (4.2)
Tricuspid aortic valve	72 (100)
Coronary artery disease	20 (27.8)
Type-A aortic dissection	
Acute	10 (13.9)
Chronic	1 (1.4)
Acute type-A intramural hematoma	1 (1.4)
Moderate/severe mitral regurgitation	3 (4.2)[a]
Mean aortic annular diameter ± SD (mm)	27.4 ± 3.1
Mean aortic root diameter ± SD (mm)	51.9 ± 8.2
Mean STJ diameter ± SD (mm)	42.8 ± 7.8
Mean ascending aortic diameter ± SD (mm)	45.5 ± 7.9
Aortic valve stenosis	0
Aortic regurgitation	
None/trace	13 (18.1)
Mild	12 (16.7)
Moderate	22 (30.6)
Severe	25 (34.7)

Abbreviations: SD, standard deviation; STJ, sinotubular junction.
Note: Categorical variables are presented as counts (%).
[a]One patient with severe regurgitation underwent mitral valve repair; two patients with moderate regurgitation preoperatively had mild or trace regurgitation postoperatively without mitral valve surgery.

Table 2 Operative data

Demographic	*n* (%)/Median (Q1–Q3)
Reimplantation of the aortic valve	72 (100)
Aortic graft diameter (mm)[a]	
26	3 (4.2)
28	10 (13.9)
30	39 (54.2)
32	18 (25)
34	2 (2.8)
Plication of free margin of aortic valve cusps	
1 cusp	8 (11.1)
2 cusps	4 (5.6)
3 cusps	1 (1.4)
Right cusp	10 (13.9)
Left cusp	4 (5.6)
Non-coronary cusp	5 (6.9)
Creation of neosinuses during reimplantation	48 (66.7)
Hemiarch replacement	38 (52.8)
Coronary artery bypass graft	17 (23.6)
Pulmonary vein isolation[b]	6 (8.3)
Left atrial appendage occlusion	
Suture ligation	2 (2.8)
Clip	4 (5.6)
PFO closure	4 (5.6)
Mitral valve repair	1 (1.4)
Resection of left atrial myxoma	1 (1.4)
Median CPB time (Q1–Q3) (min)	149 (128–177)
Median aortic clamp time (Q1–Q3) (min)	121 (107–144)

Abbreviations: CPB, cardiopulmonary bypass; PFO, patent foramen ovale; Q1, first quartile; Q3 third quartile; SD, standard deviation.
Note: Categorical variables are presented as counts (%).
[a]Mean aortic graft diameter ± SD: 30.1 ± 1.6 mm.
[b]Epicardial bipolar radiofrequency ablation.

according to the number of cells with expected count less than 5 in the respective contingency tables. Kaplan–Meier survival curves were used to analyze and plot time-related endpoints. Longitudinal analysis of serial echocardiographic data was performed with a univariate mixed-effects ordinal logistic regression model to estimate the proportion of patients in each aortic regurgitation (AR) grade over time, as well as assess for factors affecting AR. No multivariate analysis was performed due to the low number of events. The longitudinal analysis was performed using R with the GLMMadaptive package. All tests were two-sided and the level of statistical significance was set at 0.05. Cases with missing data were handled with pairwise deletion.

Results

In-hospital Outcomes

There was one case (1.4%) of in-hospital sudden death, just before discharge to a convalescence hospital, but the exact

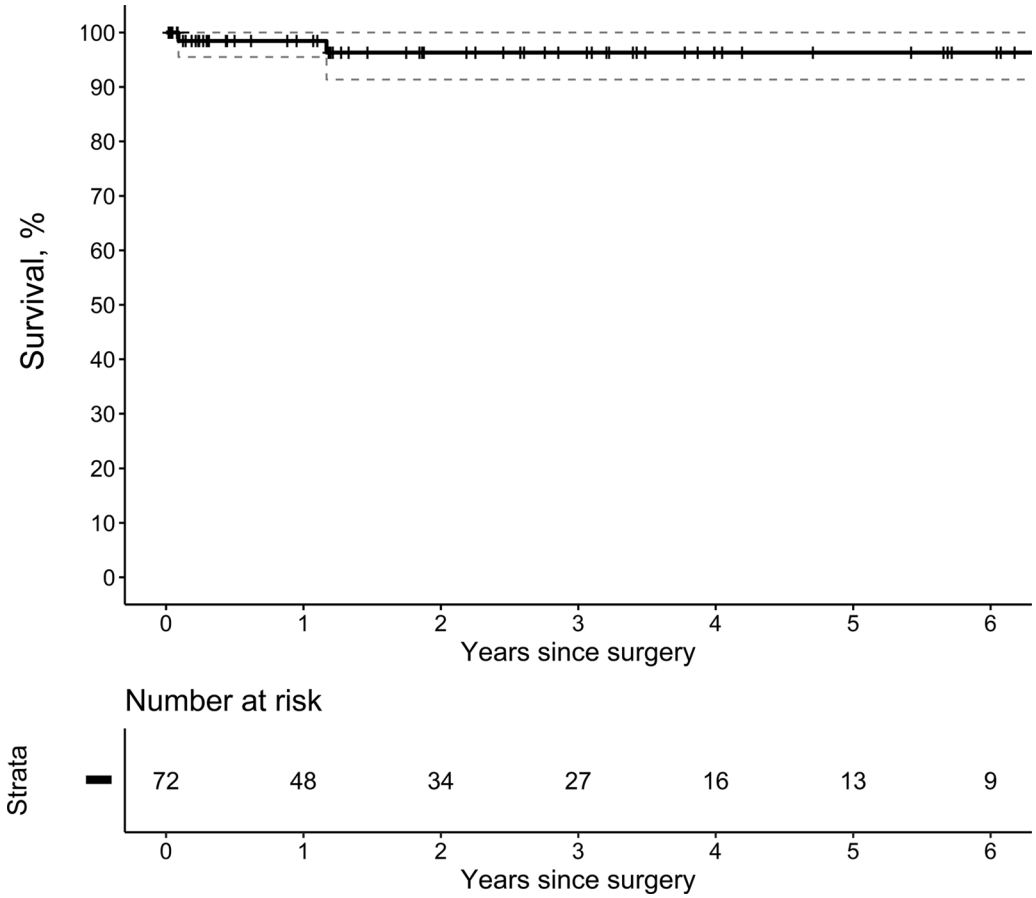


Fig. 1 Overall survival after reimplantation of the aortic valve (solid line) with 95% confidence intervals (dashed lines): 98.5 ± 1.5 and $96.3 \pm 2.5\%$ at 1 and 5 years, respectively.

cause of death is unknown. Reexploration for mediastinal bleeding or cardiac tamponade was performed in 10 patients (13.9%). There was a statistically significantly higher rate of reexploration for bleeding or tamponade in the first 3 years of performing the procedure in comparison to next years (40 vs. 7%, $p = 0.004$). One patient (1.4%) required early reoperation on the aortic valve due to severe AR caused by rupture of the left aortic cusp and underwent valve replacement. No other cases of severe or moderate AR were documented during the index hospitalization. One patient (1.4%) underwent implantation of a permanent pacemaker because of sick sinus syndrome, 4 patients (5.6%) underwent temporary renal replacement therapy because of perioperative renal failure, and 29 patients (40.3%) developed new transient atrial fibrillation. No patients had perioperative myocardial infarction, cerebrovascular thromboembolic events, deep sternal infection, or superficial wound infections. The median intubation duration was 5 hours (4–8 hours).

Midterm Outcomes

There were two deaths on the midterm, after discharge from hospital. One death due to complications associated with dementia and one death of unknown cause on a patient presenting with acute back pain on the emergency department. Survival at 1 and 5 years was 98.5 ± 1.5 and $96.3 \pm 2.5\%$, respectively (►**Fig. 1**). Two patients had transient cerebrovascular incidents at follow-up: one case of amaurosis fugax on a patient with atrial fibrillation after successful pulmonary vein isolation and occlusion of the left atrial appendage (sinus rhythm on electrocardiogram and occluded left atrial appendage on transesophageal echocardiography at the time of the event), and one case of transient ischemic attack.

Five patients (6.9%) required reoperation on the aortic valve. One patient with severe AR caused by rupture of the left aortic cusp required early reoperation and underwent valve replacement 8 days after the initial surgery. The remaining four patients required reoperation on the aortic valve later on. One patient with aortic valve endocarditis and severe AR underwent valve replacement at 18 months postoperatively. One patient with severe AR required reimplantation of the left-non-coronary commissure and plication of the left and right aortic cusps at 20 months postoperatively. One patient with periprosthetic ascending aortic graft infection required root replacement with a composite bioprosthesis at 6 months postoperatively. One patient with severe AR due to prolapse of all three cusps underwent valve replacement at 13 months postoperatively. The freedom from reoperation on the aortic valve at 1 and 5 years was 96.6 ± 2.3 and $89.9 \pm 4.3\%$, respectively (►**Fig. 2**).

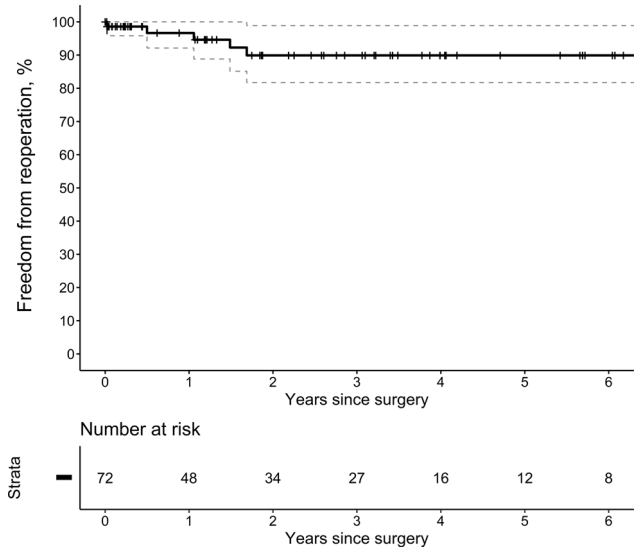


Fig. 2 Freedom from reoperation on the aortic valve after aortic valve sparing surgery (solid line) with 95% confidence intervals (dashed lines): 96.6 ± 2.3 and 89.9 ± 4.3% at 1 and 5 years, respectively.

Moderate AR developed in six patients (8.3%) and severe in four patients (5.6%) overall. The proportion of patients in each AR grade changed significantly over time ($p < 0.001$). The temporal trend of each AR grade is depicted in ►**Fig. 3** and the relevant data presented in ►**Table 3**. The presence of mild AR at discharge (odds ratio [OR] = 93.86; 95% confidence interval [CI]: 20.27–434.59; $p < 0.001$) and cusp plication (OR = 4.09; 95% CI: 1.36–12.31; $p = 0.0121$) were associated with a higher AR grade over time. Surgery urgency (OR = 0.15; 95% CI: 0.03–0.83; $p = 0.0302$) and acute type-A aortic dissection (OR = 0.12; 95% CI: 0.02–0.68; $p = 0.0161$) were associated with a lower AR grade over time. Moderate or severe AR preoperatively (OR = 2.53; 95% CI: 0.92–6.93; $p = 0.0719$), patient age (OR = 2.22; 95% CI: 0.82–6.02; $p = 0.1168$), surgeon (OR = 1.12; 95% CI: 0.24–5.16; $p = 0.8878$), aortic graft size (OR = 0.77; 95% CI: 0.29–2.04; $p = 0.6062$), and creation of aortic neosinuses (OR = 1.33; 95% CI: 0.54–3.28; $p = 0.5366$) had no effect on AR grade progression over time.

Discussion

This patient cohort exhibited a low early and midterm mortality with one in-hospital death (1.4%), a total of three documented deaths (4.2%), and a 5-year survival of 96.3 ± 2.5%. One death was non-cardiac related and two were of unknown cause. These results are similar to those of other studies and confirm the safety of the reimplantation technique.[5,9,10] The incidence of endocarditis was low with only one patient (1.4%) developing aortic valve endocarditis and requiring valve replacement at 18 months postoperatively, a finding similar to that of other published studies.[4–6,10] During the entire follow-up, only two patients (2.7%) had a cerebrovascular incident, both transient ischemic attacks, similarly low to the results of other published patient series.[4,5] The freedom from reoperation on the aortic valve at 5 years was $89.9\% \pm 4.3\%$ with five patients (6.9%) undergoing reoperation, a result comparable to that of other studies.[10,11]

The rate of reexploration for mediastinal bleeding or cardiac tamponade was 13.9%, with a statistically significantly higher rate in the first 3 years of performing the procedure in comparison to next years. However, as reported in a systematic review and meta-analysis of Arabkhani et al, the rate of reexploration for bleeding in 27 studies ranged between 0

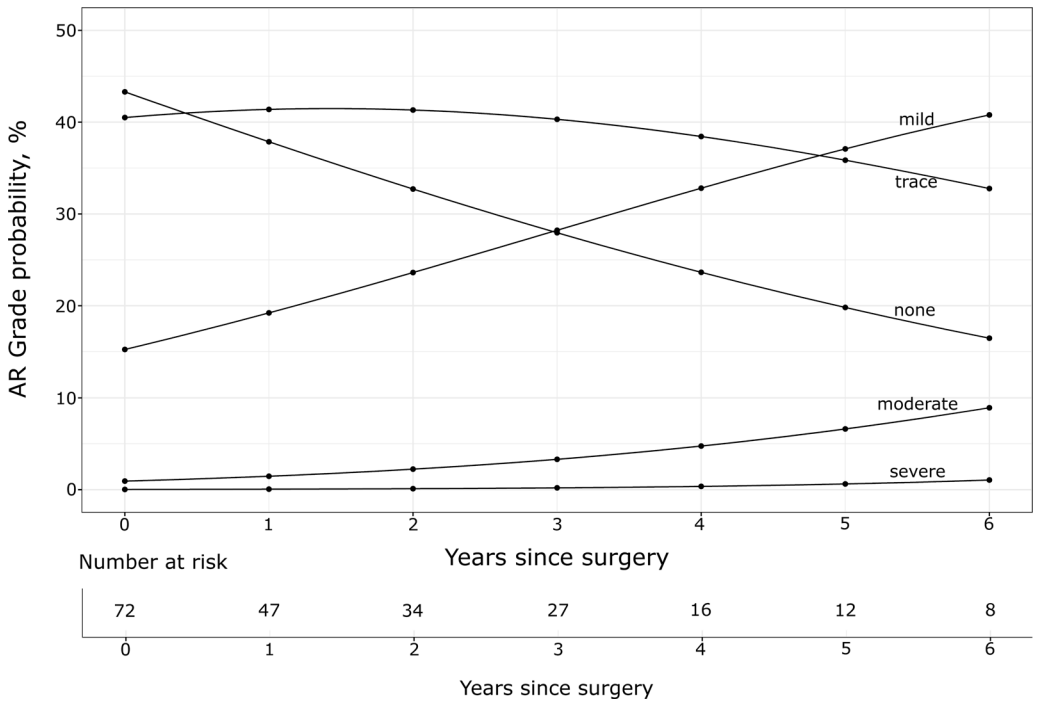


Fig. 3 Temporal trend of aortic regurgitation after aortic valve reimplantation. Severe AR at 5 years was 0.6% (95% CI: 0.1–3.2) and moderate AR at 5 years was 6.6% (95% CI: 2.4–13.6). AR: aortic regurgitation; CI: confidence interval.

Table 3 Proportion of patients in each AR grade over time

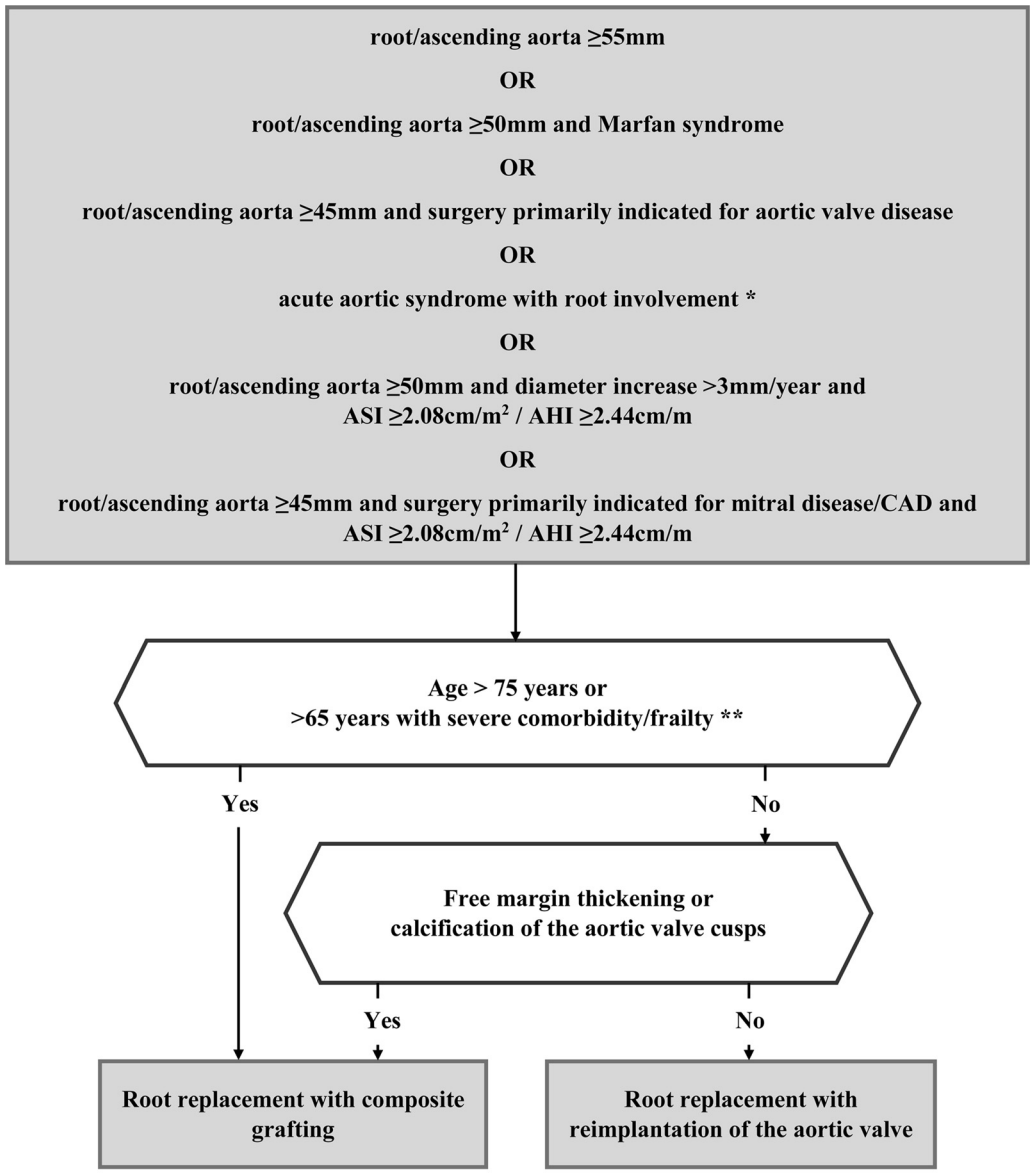
	1 year, % (95% CI)	2 years, % (95% CI)	3 years, % (95% CI)	4 years, % (95% CI)	5 years, % (95% CI)	6 years, % (95% CI)
No. of patients	47	34	27	16	12	8
AR grade						
Severe	0.1 (0–0.4)	0.1 (0–0.7)	0.2 (0–1.2)	0.4 (0.1–2)	0.6 (0.1–3.2)	1.1 (0.2–5)
Moderate	1.5 (0.5–3.6)	2.2 (0.9–5.2)	3.3 (1.2–7.3)	4.8 (1.8, 10.4)	6.6 (2.4–13.6)	8.9 (3.5–17.6)
Mild	19.2 (12.3–28.2)	23.6 (14.8–34.3)	28.2 (17.9–40.6)	32.8 (21.3–46.5)	37.1 (24.6–50.8)	40.8 (27.4–54)
Trace	41.4 (34.4–47.2)	41.3 (34.9–46.8)	40.3 (32.9–45.8)	38.4 (29–44.4)	35.9 (24.5–42.8)	32.8 (20.8–40.9)
None	37.9 (27.3–50.4)	32.7 (22.3–45.6)	28 (19–40.7)	23.6 (14.5–36.9)	19.8 (11.3–33.2)	16.5 (8.9–30.1)

Abbreviations: AR, aortic regurgitation; CI, confidence intervals.

and 23%, so that the rate of reexploration in our patient cohort lies within the published range.[6] The statistically significant reduction in the rate of reexploration for bleeding or tamponade in the last 6 years of performing the operation may be attributed to overcoming the initial learning curve associated with technical issues performing the reimplantation procedure, as reflected in a statistically significant reduction of cardiopulmonary bypass duration (median: 171 vs. 144 minutes, $p = 0.004$) and cross-clamp duration (median: 133 vs. 114 minutes, $p = 0.023$), as well as an improvement of coagulation management postoperatively.

The in-hospital postoperative echocardiography showed excellent results at discharge with no patients having moderate AR and only one patient (1.4%) having severe AR and requiring valve replacement. During follow-up, six patients (8.3%) developed moderate AR and a total of four patients (5.6%) severe AR. The longitudinal analysis of serial echocardiographic data showed that the incidence of severe AR at 5 years was 0.6% (95% CI: 0.1–3.2) and of moderate AR at 5 years was 6.6% (95% CI: 2.4–13.6), comparable to that of other published studies.[2,3]

Risk estimation and subsequent indication for operation in international guidelines is based mainly on absolute raw aortic diameter. However, using only the aortic diameter for decision-making has the disadvantage of not accounting for patient body size, a significant determinant of aortic dimensions. To address this issue, the group of Eleftheriades et al have introduced the aortic size index (ASI) and aortic height index (AHI), indexing the aortic diameter to the body surface area (BSA) and height, respectively.[12,13] In their manuscript published in 2018, they have stratified patients in four categories of yearly risk of complications based on their ASI and AHI (low: 4%, moderate: 7%, high: 12%, and severe: 18% average yearly risk of complications).[13] International societies are concerned with patient body size as a factor for surgery indication as well, and according to the aortic root chapter of the 2017 European Society of Cardiology (ESC) and European Association for Cardiothoracic Surgery (EACTS) guidelines for the management of valvular heart disease, the patient's stature should also be taken into account for individual decisions.[14] The indications for surgery in our cohort were, irrespective of the severity of aortic regurgitation and considering the presence of only tricuspid aortic valves, the following: (1) root/ascending aorta $\geq$55 mm, (2) root/ascending aorta $\geq$50 mm and Marfan syndrome, (3) root/ascending aorta $\geq$45 mm and surgery primarily indicated for aortic valve disease, (4) acute aortic syndrome with root involvement which are in accordance with the current guidelines of the ESC/EACTS.[14] Nevertheless, taking into account the patient's stature for individual decisions as proposed by the ESC/EACTS guidelines and based on the risk stratification published by the group of Eleftheriades et al, we have also performed surgery in patients with an ASI $\geq$2.08 cm/m^2 or AHI $\geq$2.44 cm/m (corresponding to an at least moderate, viz. $\geq$7% average yearly risk of complications), who also had one of the following characteristics: (1) root/ascending aorta $\geq$50 mm and diameter increase $>$3 mm/year, and (2) root/ascending aorta $\geq$45 mm and surgery



* hemodynamically unstable or >65 year-old patients with acute aortic syndrome and root involvement were treated with composite grafting
** one 76 year-old patient was deemed eligible and finally underwent aortic valve reimplantation instead of composite grafting, because of excellent health status

Fig. 4 Flow diagram describing our decision-making process and selection criteria for performing reimplantation of the aortic valve or composite grafting. AHI: aortic height index; ASI: aortic size index; CAD: coronary artery disease.

primarily indicated for mitral valve or coronary artery disease (►**Fig. 4**).[13,14]

The mean patient age of our cohort was 56.4 ± 11.2 years, as much as almost 10 years older compared with the age of other published patient cohorts.[4,5,7,10] However, age had no effect on AR grade progression over time and patients aged <65 or ≥65 years had no difference on significant AR at follow-up in our study. Even though aortic valve replacement represents the preferable treatment approach for older patients, in our opinion and considering the advantages of preserving the native aortic valve, not only advanced age but also associated comorbidities and frailty should be considered for the final decision to perform reimplantation of the aortic valve in patients with adequate cusp quality.

Controversy exists about performing reimplantation of the aortic valve in cases of acute type-A aortic dissection with root involvement. Rosenblum et al have shown that reimplantation of the aortic valve is safe in this emergency setting, with a low incidence of long-term valve-related complications.[15] In our patient series, 10 patients (13.9%) underwent reimplantation of the aortic valve because of acute type-A aortic dissection with root involvement; eight (80%) of the procedures were performed by the highest volume surgeon and the remaining two (20%) by

the second highest volume surgeon, who were the most experienced in performing this procedure overall. The decision to proceed with valve reimplantation in this setting was based on intraoperative direct inspection of the aortic cusps and the hemodynamic condition of the patient (►**Fig. 4**). In our study, acute type-A dissection was associated with a lower incidence of moderate or severe AR at follow-up, a finding most probably attributed to none of those patients requiring a cusp plication.

No patients with bicuspid aortic valves underwent the reimplantation procedure during the study period. Based on a stepwise approach, we decided to start our reconstructive aortic valve surgery program with patients having only tricuspid valve anatomy, intending to include patients with bicuspid valve anatomy in a next step. However, according to current literature, bicuspidy seems to have no impact on the results after reimplantation of the aortic valve, with well-selected patients having excellent long-term outcomes, comparable to those of patients with tricuspid aortic valves.[5,16,17]

Most patients in our cohort had significant AR preoperatively: 22 (30.6%) moderate AR and 25 (34.7%) severe AR. This proportion is higher in comparison to several other published studies involving a large number of patients.[4,11,18] Overall, moderate or severe preoperative AR is a common finding in patients undergoing valve sparing root replacement. Kari et al have found that higher grades of preoperative AR are associated with a higher rate of residual AR postoperatively.[7] However, other studies were not able to prove this association and de Kerchove et al have demonstrated that the results of valve-sparing root surgery were comparable in patients with none/mild versus severe preoperative AR.[19] Significant preoperative AR had no effect on the incidence of significant AR at follow-up in our study.

The presence of mild AR on early postoperative echocardiography is a usual finding with up to 29% of the patients having mild AR at discharge. Some authors were able to show that a significant proportion of these patients progress to moderate or severe AR, eventually requiring a reintervention on the aortic valve.[7] Other studies have found, however, that progression from mild to moderate or severe AR is unlikely and therefore mild AR should not be considered as valve dysfunction.[20] In our cohort, 16 patients (22.2%) had mild AR at discharge. Mild AR at discharge was associated with a higher rate of significant AR at follow-up with almost half of these patients (43.8%), developing significant AR at follow-up.

Aortic cusp prolapse may exist preoperatively and is a usual finding in patients with moderate or severe aortic regurgitation. Cusp prolapse may also arise postoperatively after the reimplantation of aortic valves with increased cusp size in cases of enlarged sinotubular dimensions.[21] Free margin cusp plication performed during valve preserving root replacement may address the issue of cusp prolapse. Some authors have found that cusp plication does not have a negative impact on the long-term incidence of significant AR and even proves beneficial, allowing valve preserving surgery in patients with leaflet prolapse.[4,11,19,22] However, not all studies came to the same findings. Burkhart et al have shown a high failure rate in patients undergoing reimplantation of the aortic valve and additional cusp repair.[23] Another important issue affecting the durability of the reimplanted aortic valve is the level of coaptation of the aortic cusps in relation to the aortic annulus. Schäfers et al advocate for the intraoperative use of a caliper for the accurate and reproducible measurement of the effective cusp height.[21] In our cohort, assessment for cusp prolapse was performed with transesophageal echocardiography and visual inspection before and after reimplantation of the aortic valve. Accordingly, 13 patients (18.1%) underwent additional cusp plication. Cusp plication was associated with a higher incidence of moderate or severe AR at follow-up and 23.1% of these patients developed significant AR at follow-up.

The presence of aortic sinuses either with creation of neosinuses through plication of a straight tubular graft or with the implantation of a commercially available graft with aortic sinuses is controversially discussed in the literature. David et al have gone over the years from the use of straight tubular grafts, to creation of neosinuses through plication of straight grafts and then back to the use of straight tubular grafts, arguing that even though with unphysiological properties, the results of the reimplantation of the aortic valve on a straight graft remain the best and most durable, based on their follow-up.[4,9] In our report, 48 patients (66.7%) had creation of aortic neosinuses through plication of a straight tubular graft, with data analysis showing no difference in the rate of moderate or severe AR at follow-up between patients with or without neosinuses.

Root replacement with reimplantation of the aortic valve is a complex procedure and most of the published results are based on the data generated by a small number of surgeons who performed the great majority of the procedures in a small number of high-volume centers.[4,5] Therefore, questions arise about the reproducibility of this complex technique and the subsequent generalizability of the published results. A study comparing the long-term outcomes of high- and low-volume surgeons found no difference in valve-related complications, suggesting long-term durability even with limited surgeon experience.[24] In our series, one surgeon performed surgery on 46 patients (63.8%), one surgeon on 19 patients (26.4%), and four surgeons performed the rest of the procedures. The two highest volume surgeons were operating evenly throughout the first and the second half of the study period and were the most experienced in performing this procedure, even though the other four surgeons were able to perform it as well. In spite of the infrequent performance of the procedure from four surgeons, no difference in midterm outcomes between the highest volume surgeons and the other four surgeons was observed.

Study Limitations

This study has limitations, first being retrospective and second having a low number of events for the main valve-related outcomes. The low number of events for the endpoints of death and reoperation on the aortic valve precluded any robust statistical analysis for factors associated with these events. The number of events for the endpoint of moderate or severe AR at follow-up allowed a rather meaningful univariate analysis of factors possibly associated

with this endpoint, but no robust multivariate analysis was possible. Finally, the median follow-up time was relatively short with no patients having a follow-up time over 8.3 years, so that no 10-year results were available.

Conclusion

This study shows that root replacement with reimplantation of the aortic valve is safe and feasible even in a low-volume center with mortality, freedom from reoperation on the aortic valve and freedom from moderate or severe AR at midterm follow-up comparable to those of high-volume centers. Mild AR at hospital discharge and cusp plication were associated with a higher incidence of recurrent significant AR at follow-up.

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Conflict of Interest Statement
None declared.

References

1 David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. J Thorac Cardiovasc Surg 1992;103(04):617–621, discussion 622
2 Stamou SC, Williams ML, Gunn TM, Hagberg RC, Lobdell KW, Kouchoukos NT. Aortic root surgery in the United States: a report from the Society of Thoracic Surgeons database. J Thorac Cardiovasc Surg 2015;149(01):116–22.e4
3 Schäfers HJ. Aortic valve repair: easy and reproducible? J Thorac Cardiovasc Surg 2015;149(01):129–130
4 David TE, David CM, Feindel CM, Manlhiot C. Reimplantation of the aortic valve at 20 years. J Thorac Cardiovasc Surg 2017;153(02):232–238
5 Mastrobuoni S, de Kerchove L, Navarra E, et al. Long-term experience with valve-sparing reimplantation technique for the treatment of aortic aneurysm and aortic regurgitation. J Thorac Cardiovasc Surg 2019;158(01):14–23
6 Arabkhani B, Mookhoek A, Di Centa I, et al. Reported outcome after valve-sparing aortic root replacement for aortic root aneurysm: a systematic review and meta-analysis. Ann Thorac Surg 2015;100(03):1126–1131
7 Kari FA, Doll KN, Hemmer W, et al. Residual and progressive aortic regurgitation after valve-sparing root replacement: a propensity-matched multi-institutional analysis in 764 patients. Ann Thorac Surg 2016;101(04):1500–1506
8 Clark TG, Altman DG, De Stavola BL. Quantification of the completeness of follow-up. Lancet 2002;359(9314):1309–1310
9 David TE, Armstrong S, Manlhiot C, McCrindle BW, Feindel CM. Long-term results of aortic root repair using the reimplantation technique. J Thorac Cardiovasc Surg 2013;145(3, suppl):S22–S25
10 Shrestha ML, Beckmann E, Abd Alhadi F, et al. Elective David I procedure has excellent long-term results: 20-year single-center experience. Ann Thorac Surg 2018;105(03):731–738
11 Liebrich M, Kruszynski MK, Roser D, et al. The David procedure in different valve pathologies: a single-center experience in 236 patients. Ann Thorac Surg 2013;95(01):71–76
12 Davies RR, Gallo A, Coady MA, et al. Novel measurement of relative aortic size predicts rupture of thoracic aortic aneurysms. Ann Thorac Surg 2006;81(01):169–177
13 Zafar MA, Li Y, Rizzo JA, et al. Height alone, rather than body surface area, suffices for risk estimation in ascending aortic aneurysm. J Thorac Cardiovasc Surg 2018;155(05):1938–1950
14 Baumgartner H, Falk V, Bax JJ, et al; ESC Scientific Document Group. 2017 ESC/EACTS Guidelines for the management of valvular heart disease. Eur Heart J 2017;38(36):2739–2791
15 Rosenblum JM, Leshnower BG, Moon RC, et al. Durability and safety of David V valve-sparing root replacement in acute type A aortic dissection. J Thorac Cardiovasc Surg 2019;157(01):14–23.e1
16 Beckmann E, Martens A, Krüger H, et al. Aortic valve-sparing root replacement in patients with bicuspid aortic valve: long-term outcome with the David I procedure over 20 years. Eur J Cardiothorac Surg 2020;58(01):86–93
17 Ouzounian M, Feindel CM, Manlhiot C, David C, David TE. Valve-sparing root replacement in patients with bicuspid versus tricuspid aortic valves. J Thorac Cardiovasc Surg 2019;158(01):1–9
18 Leontyev S, Schamberger L, Davierwala PM, et al. Early and late results after David vs Bentall procedure: a propensity matched analysis. Ann Thorac Surg 2020;110(01):120–126
19 de Kerchove L, Boodhwani M, Glineur D, et al. Effects of preoperative aortic insufficiency on outcome after aortic valve-sparing surgery. Circulation 2009;120(11, suppl):S120–S126
20 Stephens EH, Liang DH, Kvitting JP, et al. Incidence and progression of mild aortic regurgitation after Tirone David reimplantation valve-sparing aortic root replacement. J Thorac Cardiovasc Surg 2014;147(01):169–177, 178.e1–178.e3
21 Schäfers HJ, Aicher D. Root remodeling for aortic root dilatation. Ann Cardiothorac Surg 2013;2(01):113–116
22 Schäfers HJ, Aicher D, Langer F. Correction of leaflet prolapse in valve-preserving aortic replacement: pushing the limits? Ann Thorac Surg 2002;74(05):S1762–S1764, discussion S1792–S1799
23 Burkhart HM, Zehr KJ, Schaff HV, Daly RC, Dearani JA, Orszulak TA. Valve-preserving aortic root reconstruction: a comparison of techniques. J Heart Valve Dis 2003;12(01):62–67
24 Tkebuchava S, Tasar R, Lehmann T, et al. Predictors of outcome for aortic valve reimplantation including the surgeon-a single-center experience. Thorac Cardiovasc Surg 2020;68(07):567–574