The Freedom Solo pericardial stentless valve: Single-center experience, outcomes, and long-term durability

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ABSTRACT

Objectives: To report our institutional experience and long-term results with the Freedom Solo bovine pericardial stentless bioprosthesis (Sorin Group, Saluggia, Italy).

Methods: Between January 2005 and November 2009, 149 patients (mean age, 73.6 ± 8.7 years; 68 [45.6%] female) underwent isolated ($n = 75$) or combined ($n = 74$) aortic valve replacement (AVR) using the Solo in our institution. Follow-up was 100% complete with an average follow-up time of 5.9 ± 2.6 years (maximum, 9.6 years) and a total of 885.3 patient years.

Results: Operative (30-day) mortality was 2.7% (1.3% for isolated AVR [$n = 1$] and 4.0% for combined procedures [$n = 3$]). All causes of death were not valve-related. Preoperative peak (mean) gradients of 74.2 ± 23.0 mm Hg (48.6 ± 16.3 mm Hg) decreased to 15.6 ± 5.4 mm Hg (8.8 ± 3.0 mm Hg) after AVR, and remained low for up to 9 years. The postoperative effective orifice area was 1.6 ± 0.57 cm², 1.90 ± 0.45 cm², 2.12 ± 0.48 cm², and 2.20 ± 0.66 cm² for the valve sizes 21, 23, 25, and 27, respectively, with absence of severe prosthesis-patient mismatch and 0.7% ($n = 1$) experienced moderate prosthesis-patient mismatch. During follow-up, 26 patients experienced structural valve deterioration (SVD) and 14 patients underwent explantation. Kaplan-Meier estimates for freedom from death, explantation, and SVD at 9 years averaged 0.57 (range, 0.47-0.66), 0.82 (range, 0.69-0.90), and 0.70 (range, 0.57-0.79), respectively.

Conclusions: The Freedom Solo stentless aortic valve is safe to implant and shows excellent early and midterm hemodynamic performance. However, SVD was observed in a substantial number of patients after only 5-6 years and the need for explantation increased markedly, suggesting low durability. (J Thorac Cardiovasc Surg 2015;150:70-7)

Freedom from SVD, explantation for SVD, and cumulative failure.

Central Message

The Freedom Solo stentless aortic valve (Sorin Group, Saluggia, Italy) is safe to implant with excellent early and midterm hemodynamic performance. However, structural valve deterioration was observed in a substantial number of patients after only 5 to 6 years and the need for explantation increased markedly, suggesting lower-than-expected durability.

Perspective

The Freedom Solo aortic valve (Sorin Group, Saluggia, Italy) is safe to implant and represents the most advanced stentless bioprosthesis available. However, in our single-institution experience, an unexpectedly high amount of valve-independent dysfunction or valve-dependent failure was observed. Any malpositioning and asymmetry between the native anatomy and the stentless tissue valve may cause small distortions and increased chronic mechanical stress, potentially leading to fatigue over time and premature valve deterioration. Root anatomy, correct sizing, symmetric implantation, and tension-free positioning must receive particular attention when using a Solo device.

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Abbreviations and Acronyms

AVR	= aortic valve replacement
BSA	= body surface area
EOA	= effective orifice area
EuroScore II	= European System for Cardiac Operative Risk Evaluation II
GA	= glutaraldehyde
HCA	= homocysteic acid
LVEF	= left ventricular ejection fraction
PPM	= prosthesis-patient mismatch
SVD	= structural valve deterioration

Stentless bioprostheses were introduced as an attractive alternative to stented valves, combining the advantages of nonobstructive effective orifice area (EOA) and a flexible aortic root that was believed to be essential for natural leaflet stress distribution. Correspondingly, unstented xenografts, with minimal disruption of the aortic root anatomy and function, are expected to reduce dynamic stress on leaflets thereby limiting valve degeneration and failure.¹ Whereas some earlier stentless porcine root prostheses showed unsatisfactory results with premature failure,²⁻⁴ more advanced models were aimed at optimizing the tissue type, preservation, and anticalcification treatments, as well as valve design.

The third-generation bovine pericardium Freedom Solo (henceforth Solo) stentless bioprosthesis (Sorin Group, Saluggia, Italy) emerged as a modified version of the Pericarbon Freedom stentless valve in 2004,⁵ and has recently received Food and Drug Administration approval for use in the United States (June 24, 2014). The prosthesis is made of 2 bovine pericardial sheets for supraannular subcoronary implantation using only 1 single suture line, thus reducing crossclamp time. Furthermore, the Solo is manufactured with a unique process that includes homocysteic acid (HCA) as an anticalcification treatment to bind and neutralize free glutaraldehyde (GA) residues for optimal durability.

Numerous reports have documented superior early and midterm hemodynamic results for stentless valve prostheses, including the Solo, in comparison to stented bioprostheses.⁶⁻¹⁰ Although the Solo stentless valve has been used since 2004, no long-term outcome data (beyond the mean 1.2 ± 0.8 years) are available.¹⁰ Thus, we are only now reaching an observation period that allows evaluation of long-term outcome, particularly durability, which will eventually define noninferiority compared with available alternative stented bioprostheses. Because our institution introduced the Solo stentless bioprosthesis at a particularly early stage, we report our operative results with the aim of assessing long-term clinical results; that is, durability and freedom from major adverse events after up to 9.6 years of follow-up.

TABLE 1. Patient preoperative characteristics

Characteristic	Result
Number of patients	149
Age, y	73.6 $\pm$ 8.7 (46.1-87.4)
Gender	
Male	81 (54.4)
Female	68 (45.6)
Body mass index	27.0 $\pm$ 5.9 (16.9-29.4)
Body surface area, m ²	1.82 $\pm$ 0.29 (1.27-2.20)
Diabetes mellitus	34 (22.8)
Arterial hypertension	130 (87.2)
Renal impairment	24 (16.1)
Peripheral artery disease	62 (41.1)
Carotid stenosis	14 (10.1)
Chronic obstructive pulmonary disease	25 (9.4)
Left ventricular ejection fraction, %	55.4 $\pm$ 12.3
History of cerebral events	17 (11.4)
New York Heart Association functional class	
I	14 (9.4)
II	62 (41.6)
III	54 (36.2)
IV	19 (12.8)
Valve pathology	
Stenosis	126 (84.6)
Regurgitation	10 (6.7)
Combined	13 (8.7)
Preoperative rhythm	
Sinus data	120 $\pm$ 80.5
Chronic atrial fibrillation	21 (14.1)
Heart block	2 (1.3)
Paced	6 (4.0)
European System for Cardiac Operative Risk Evaluation II score	
Total	5.70 $\pm$ 8.88
Isolated aortic valve replacement	2.69 $\pm$ 3.36
Combined procedures	8.67 $\pm$ 11.34

Values are presented as mean $\pm$ standard deviation (range) or n (%).

MATERIALS AND METHODS**Patient Population**

Between January 2005 and November 2009, 149 patients (mean age, 73.6 ± 8.7 years; 68 female [45.6%]) underwent isolated (n = 75) or combined (n = 74) aortic valve replacement (AVR) using the Solo bovine pericardial stentless valve bioprosthesis in our institution. The decision to use the Solo stentless valve or an alternative, conventional stented prosthesis was at the surgeon's discretion. The Solo stentless valve was not considered suitable in cases with severe calcification of the aortic root, and in patients with true bicuspid valve and ectasia of the ascending aorta. The local ethics committee approved the review of patient data and patient consent was waived for the retrospective analysis. The patients' characteristics are shown in Table 1. One patient underwent operation due to acute bacterial endocarditis (*Staphylococcus aureus*), and 4 cases were re-do procedures. At the time of surgery, left ventricular ejection fraction (LVEF) $\leq 40\%$ was present in 24 patients (16.1%).

Surgical and Postoperative Management

AVR procedures were all performed under routine general anesthesia and with a median sternotomy, using standard cardiopulmonary bypass and mild hypothermia (34°C). Cold blood cardioplegia was routinely

used for myocardial protection. Aortotomy was performed approximately 1 cm above the sinotubular junction. The diseased valve was then excised and the annulus carefully decalcified. The Solo valve was implanted without rinsing in the supraannular subcoronary position, with 3 continuous suture lines using 4-0 Prolene polypropylene monofilament (Ethicon, Somerville, NJ) as reported in detail elsewhere.¹¹ In brief, sutures started at the base of each sinus, continued to the top of the commissures, and ended with extraaortic fixation. Transesophageal echocardiography was routinely performed intraoperatively before and after AVR to assess the function of the prosthesis. No oral anticoagulation after hospital discharge was required in patients with the Solo valve.

Data Collection, Follow-up, and Definitions

Perioperative data were retrieved from our prospectively managed institutional database (Dendrite Clinical Systems LTD, Henley-on-Thames, United Kingdom). Closing date for all follow-up investigations was October 1, 2014. Follow-up was 100% complete with an average follow-up time of 5.9 ± 2.6 years (maximum, 9.6 years) and a total of 885.3 patient years.

All patients were routinely examined with transthoracic echocardiography before hospital discharge, at 6 months postoperatively, and yearly thereafter. Intervals were shortened when changes or signs of degeneration were observed. Transvalvular pressure gradients and EOA were calculated using the modified Bernoulli equation and the continuity equation, respectively. Clinical status and adverse events were carefully assessed at each visit or by consultation with the referring physician. Dates of death were confirmed with data from local public authorities.

Data Analysis

Baseline characteristics and risk factors were defined according to European System for Cardiac Operative Risk Evaluation II (EuroScore II) criteria. Mortality and morbidity (rate of adverse events) were reported according to established guidelines.^{12,13} These guidelines define structural valve deterioration (SVD) as change in function or deterioration of an operated valve resulting from an intrinsic abnormality of the valve that causes stenosis or regurgitation, exclusive of infection or thrombosis. SVD includes wear, fracture, poppet escape, calcification, leaflet tear, stent creep, and suture line disruption of an operated valve.^{12,13} In the absence of established reference values for prosthetic SVD, particularly for stentless valves, we defined intrinsic prosthetic stenosis under normal flow conditions (ejection fraction > 50%) and after normal postoperative function, when echocardiographic evidence of distinctive and pronounced degenerative changes (such as severely impaired cusp movements due to thickened, sclerosed, or calcified leaflets) was present (repeat measurements with different investigators) and at least 2 of the following criteria were met: ≥ 3 -fold increase of mean gradients compared with early postoperative measurements (before discharge) in ≥ 25 mm Hg mean gradient; EOA < 1.5 cm^2 , indexed EOA < $0.9 \text{ cm}^2/\text{m}^2$, and peak velocity $\geq 3 \text{ m/sec}$ or velocity time integral of 0.5 to 0.25 (velocity time integral was measured in the left ventricular outflow tract and the aortic valve and expressed as left ventricular outflow tract/aortic valve). SVD due to regurgitation was defined as at least moderate regurgitation with pressure half time ≤ 500 ms and width of vena contracta ≥ 5 mm (if limited to 1 jet) or diastolic flow reversal in the descending or abdominal aorta in combination with echocardiographic evidence of abnormal prosthesis structure or motion. According to the generally accepted concept of prosthesis-patient mismatch (PPM), the best variable for defining PPM is the ratio of prosthetic EOA to the patient's body surface area (BSA).¹⁴ PPM was defined as an indexed EOA between $0.85 \text{ cm}^2/\text{m}^2$ and $0.65 \text{ cm}^2/\text{m}^2$ (moderate) and $< 0.65 \text{ cm}^2/\text{m}^2$ (severe), which are the established cutoff values for all types of prosthetic valves.¹⁴

Statistical Analysis

Demographic data are presented as mean values and standard deviation for continuous variables, and by number and percentages for categorical

TABLE 2. Operative data

Variable	Result
Procedure	149
Isolated aortic valve replacement	75
Combined procedures*	74
Coronary artery bypass grafting	59
Grafts	1.9 ± 1.0
Coronary artery bypass graft + mitral valve repair/replacement	5
Coronary artery bypass graft + tricuspid valve repair	1
Mitral valve repair/replacement (double valve replacement)	1
Mitral valve repair/replacement (double valve replacement) + tricuspid valve repair	1
Tricuspid annuloplasty	1
Ascendens tube graft	3
Ablation	2
Persistent foramen ovale-closure	8
Other	4
Labeled valve size	
#19	3 (2.0)
#21	28 (18.8)
#23	44 (29.5)
#25	39 (26.2)
#27	35 (23.5)
Cardiopulmonary bypass time, min	
Isolated procedures	64 ± 14
Combined procedures	95 ± 31
Crossclamp time, min	
Isolated procedures	47 ± 13
Combined procedures	71 ± 23
Red blood cell units†	
Isolated procedures	2.4 ± 1.3
Combined procedures	3.2 ± 2.1
Platelets‡	
Isolated procedures	1.5 ± 0.9
Combined procedures	1.8 ± 1.1
30-d mortality	
Isolated procedures	1/75 (1.3)
Combined procedures	3/74 (4.0)
Overall	4/149 (2.7)

Values are presented as n, mean $\pm$ standard deviation, or n (%). *One or more concomitant procedures. †51.1% of patients received ≥ 1 unit. ‡14.4% of patients received ≥ 1 unit.

variables. Outcome data are presented as operative mortality, defined as death from any cause during or after surgery within 30 days if the patient was discharged, or within any interval if the patient was not discharged,¹² or as Kaplan-Meier estimates of freedom from the following end points: death, SVD, explantation, thrombosis, endocarditis, or a combination of all. We used multivariate Cox proportional hazard ratio models to identify associations between patient- or procedure-related factors and end points. We used 2 linear mixed models, the first to analyze the effect of the valve replacement on the mean gradient, and the second to analyze the time effect on the mean gradient. Inspecting the residual plots with respect to the random and fixed effects, we detected outliers in the second model corresponding to those patients who developed SVD. Because these patients provide particularly important information, we accepted the larger variance. All *P* values and confidence intervals are 2-sided. All statistical analyses were performed using Stata (version 12, StataCorp, College Station, Tex).

RESULTS

Operative Data, Mortality, and Early Complications

The mean extracorporeal circulation and crossclamp times were, respectively, 64 ± 14 minutes (range, 47 ± 13 minutes) and 95 ± 31 minutes (range, 71 ± 23 minutes) for isolated and combined procedures, with no significant differences among sizes 21, 23, 25, and 27. All patients left the operating room with no or trivial regurgitation.

Overall operative (in-hospital) mortality was 2.7% (1.3% for isolated AVR [$n = 1$] and 4.0% for combined procedures [$n = 3$]). The corresponding EuroScore II score overestimated the observed mortality considerably (Table 1). Causes of early death were not valve-related; that is, low cardiac output and myocardial infarction ($n = 3$) and embolism of the basilar artery ($n = 1$) (Table 2). The 4 nonsurviving patients were older (77.9 ± 2.6 years vs 73.4 ± 0.7 years; $P = .038$) and had a significantly higher EuroScore II score (20.42 ± 20.74 vs 5.29 ± 8.12 ; $P < .001$) compared with the 145 surviving patients.

In total, 25 patients experienced in-hospital complications (multiple complications possible), including temporary hemofiltration therapy for renal failure (of which 4 patients had renal impairment preoperatively). There were 8 cerebral events, 7 of which were fully reversible by the time of hospital discharge (3 patients had previously experienced cerebral events). Five patients required drainage for pericardial or pleural effusions. There were 2 sternal reexplorations for impaired sternal healing. One permanent pacemaker was implanted due to complete atrioventricular block. Including all patients with these early complications combined, the discharge from hospital occurred after a median length of stay of 10.0 days and 10.5 days for isolated and combined procedures, respectively.

Hemodynamic and Hematologic Data

The mean preoperative LVEF of $55.4\% \pm 12.3\%$ improved to $58.6\% \pm 11.1\%$, $61.5\% \pm 12.7\%$, $61.7\% \pm 10.1\%$, $62.4\% \pm 10.1\%$, and $63.0\% \pm 8.5\%$ at 6 months, 1, 2, 3, and 4 years postoperatively, respectively ($P < .001$). Preoperative peak gradients of 76.3 ± 25.3 mm Hg decreased to 17.9 ± 9.8 mm Hg postoperatively. Mean gradients decreased by -39.2 mm Hg ($P < .001$; 95% confidence interval [CI], -42.4 to -35.9 mm Hg) on average in every patient following AVR (Figure 1). Following the first postoperative measurement, the mean gradient increased by 0.94 mm Hg ($P < .001$; 95% CI, 0.74 - 1.1) per year, but this was driven by 12 patients who reached a mean gradient > 30 mm Hg. Gradients showed a nonsignificant trend for lower values with increasing valve size. The postoperative EOA (mean $\pm$ standard deviation) for the valve sizes 21, 23, 25, and 27 were 1.67 ± 0.57 cm², 1.90 ± 0.45 cm², 2.12 ± 0.48 cm², and 2.20 ± 0.66 cm², respectively. With the definition of PPM as the ratio

FIGURE 1. Gradients.

of prosthetic EOA to the patient's BSA and the use of established cut-off values,¹⁴ severe PPM was completely absent, and moderate PPM occurred in 1 patient (0.7%); however body mass index was 37.7 and BSA was 2.02.

Daily platelet counts were performed as part of the standard patient management protocol. Excluding patients with heart failure, infection, and reexploration, minimum platelet counts occurred following an average decrease of 59.9%. After reaching a nadir on the second postoperative day, platelet count returned to baseline value, on average, on the eighth postoperative day. No excess or unexpected bleeding or reexploration was associated with the Solo valve.

Long-Term Survival and Freedom from Major Adverse Events

Fifty-four patients died during the follow-up period. The survival rate at 7, 8, and 9 years was 66%, 59%, and 57%, respectively (see Table 3 and Figure 2). Multivariate Cox regression analysis identified age (hazard ratio [HR], 1.06; 95% CI, 1.02-1.11; $P = .008$) and renal dysfunction (HR, 1.94; 95% CI, 1.02-3.68; $P = .044$) as parameters independently associated with survival, in contrast to arterial hypertension (HR, 2.75; 95% CI, 0.85-8.85; $P = .091$), concomitant coronary artery bypass grafting (HR, 1.18; 95% CI, 0.70-2.05; $P = .544$), combined procedures (HR, 1.12; 95% CI, 0.65-1.93; $P = .680$), and indexed PPM (EOA/BSA as continuous variable: HR, 1.00; 95% CI, 0.73-13.76; $P = 1.000$).

In 14 patients, the Solo prostheses required explantation due to valve-independent dysfunction ($n = 5$); that is, thrombus formation, oversizing, aortic dilation, endocarditis, and suture dehiscence or valve-dependent failure ($n = 9$) and all cases are reported separately in great detail elsewhere.¹⁵ In brief, 5 solo devices required explantation due to severe functional stenosis and gross calcification that was always strikingly severe and included the entire aortic root. Four cases presented with acute regurgitation due to leaflet rupture, all of which were size 23 and 25

TABLE 3. Estimates on freedom from major adverse events

Estimate	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Freedom from										
Death	0.94 (0.89-0.97)	0.91 (0.85-0.94)	0.86 (0.80-0.91)	0.80 (0.73-0.86)	0.75 (0.67-0.81)	0.69 (0.61-0.76)	0.66 (0.57-0.73)	0.59 (0.50-0.68)	0.57 (0.47-0.66)	0.57 (0.47-0.66)
SVD	1.00 (1.00-1.00)	0.99 (0.94-1.00)	0.99 (0.94-1.00)	0.97 (0.92-0.99)	0.92 (0.86-0.96)	0.88 (0.81-0.93)	0.81 (0.72-0.88)	0.73 (0.62-0.81)	0.70 (0.57-0.79)	0.60 (0.37-0.77)
Explantation	0.99 (0.95-1.00)	0.96 (0.92-0.99)	0.96 (0.92-0.99)	0.96 (0.91-0.98)	0.95 (0.89-0.97)	0.95 (0.89-0.97)	0.92 (0.86-0.96)	0.85 (0.75-0.92)	0.82 (0.69-0.90)	0.82 (0.69-0.90)
Explantation for SVD	1.00 (1.00-1.00)	0.99 (0.94-1)	0.99 (0.94-1.00)	0.99 (0.94-1.00)	0.98 (0.93-0.99)	0.98 (0.93-0.99)	0.95 (0.88-0.98)	0.88 (0.77-0.94)	0.84 (0.71-0.92)	0.84 (0.71-0.92)
Endocarditis	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.98 (0.93-0.99)	0.98 (0.93-0.99)	0.98 (0.93-0.99)	0.98 (0.93-0.99)	0.97 (0.93-0.99)	0.97 (0.91-0.99)	0.97 (0.91-0.99)	0.97 (0.91-0.99)
Thromboembolism	0.99 (0.99-0.93)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)	0.99 (0.95-1.00)
Combined overall failure	0.93 (0.87-0.96)	0.88 (0.82-0.92)	0.84 (0.77-0.89)	0.77 (0.69-0.83)	0.69 (0.61-0.76)	0.60 (0.52-0.68)	0.53 (0.45-0.61)	0.45 (0.36-0.53)	0.41 (0.31-0.50)	0.35 (0.22-0.48)

Values are presented as estimate (range). SVD, Structural valve deterioration.

prostheses. In all these cases of nonsclerotic SVD, vertical tears were notably located in close proximity to the noncoronary/right-coronary commissure, and in our series they occurred, on average, 1.5 years (6.0 vs 7.5 years) earlier than explantation for degenerative stenosis. Two patients (14.3%) did not survive reoperation: 1 due to sudden cardiac arrest of unknown cause on the eighth postoperative day, and the second because of right ventricular failure.

There were 26 cases of SVD documented during the follow-up period (see Figure 2 and Table 3), of which only 10 underwent reoperation. The remaining 16 patients did not undergo reoperation because of presumed excessive surgical risk, stable valve dysfunction, or because the patient declined surgical treatment. Multivariate Cox regression analysis identified younger age (HR, 0.93; 95% CI, 0.89-0.97; $P = .002$) as an independent predictor for SVD, but not renal dysfunction (HR, 1.15; 95% CI, 0.26-5.14; $P = .855$), diabetes (HR, 1.39; 95% CI, 0.54-3.55; $P = .495$), arterial hypertension (HR, 2.60; 95% CI, 0.620-10.80; $P = .189$), nor PPM (EOA/BSA) as continuous variable (HR, 0.10; 95% CI, 0.10-7.26; $P = .855$).

Four patients experienced endocarditis, 2 of whom underwent valve explantation and replacement, and the 2 other patients did not undergo reoperation and died 3 and 8 months after diagnosis, respectively. One patient presented with a large thrombotic adhesion on the noncoronary commissure and underwent reoperation 5 months after the primary AVR.

Combining all end points, 78 (52%) patients experienced an event. We included age, gender, isolated procedure, hypertension, indexed EOA, renal dysfunction, diabetes, and EuroScore II in a Cox regression analysis with the combined end point; only EuroScore II showed an association (HR, 1.02; 95% CI, 0.02-1.00; $P = .018$), suggesting heterogeneous associations between independent variables and individual end points, and indicating

that no patient- or procedure-specific parameter alone permits prediction of prosthesis failure.

DISCUSSION

We are reporting our clinical results in a cohort of 149 patients with the longest follow-up available to date for the third-generation Solo stentless bioprosthesis. Our data suggest that the valve is safe to implant, and provides an excellent early hemodynamic performance. However, freedom from SVD and explantation decreased markedly in our single center study after only 5 to 6 years, implying that the Solo durability is considerably lower than that of conventional stented prostheses.

The Solo represents the most advanced stentless bioprosthesis that combines the single-suture, subcoronary implantation technique with the latest-generation bovine pericardial tissue and a novel anticalcification treatment. Consistent with previous reports,⁷⁻¹⁰ we demonstrate excellent early results of the Solo, relatively easy implantation with acceptable crossclamp times, low gradients, and large EOA, as well as near absence of PPM.

As a unique Solo-dependent side effect, and consistent with previous reports,^{7,8,10,16,17} we observed postoperative thrombocytopenia following implantation, with a mean decrease of 59.9% in platelet numbers on the second postoperative day, followed by full recovery within 8 days. Importantly, and unexpectedly, Solo-related excess bleeding complications, thromboemboli, or increased reexploration rates have not been observed despite this transient thrombocytopenia. Furthermore, there is no evidence for excess platelet activation, platelet consumption, or change in postoperative platelet function.¹⁸ Causal hemodynamic flow-dependent mechanical damage appears highly unlikely given the large EOA and low gradients with correctly sized Solo valves, with performances similar to

FIGURE 2. Kaplan-Meier estimates for major adverse events. SVD, Structural valve deterioration.

native aortic valves at rest and under stress conditions.^{9,19} Contrary to observation, the platelet-damaging effect would be expected to persist if Solo-related hemodynamic stress was causal. In agreement with the suggestion of a patient-independent effect derived from a study with a propensity-matched design,¹⁷ we hypothesize that a temporary, chemistry-induced lysis leads to lower platelet counts in patients with the Solo device, although the precise mechanism of thrombocytopenia remains to be identified.

A number of stentless valve prostheses have been developed and introduced, but all have been fundamentally different with respect to design, tissue type, and anticalcification treatment, rendering comparisons difficult. Concerns have been raised for stentless prostheses regarding long-term durability, most likely resulting from experiences with earlier (porcine root) models for which, after approximately 10 years, freedom from SVD and reoperation dropped dramatically; for example, the O'Brien (CryoLife, Atlanta, Ga),² Shelhigh (Shelhigh, Inc, Millburn, NJ),³ Biocor (St Jude Medical, St Paul, Minn),²⁰ and Toronto SPV⁴ (St Jude Medical, St Paul, Minn).

In our single institution experience freedom from thromboembolism and endocarditis was high and comparable to that reported for other stentless and stented bioprosthesis,²¹⁻²⁵ but freedom from SVD and explantation in our series was much lower than expected. Freedom from explantation after 9 years was only 0.82 in our cohort, compared with 0.97 and 0.98 reported for the conventional stented Hancock II (Medtronic Inc, Minneapolis, Minn)^{22,23} and Perimount Magna (Edwards Lifesciences, Irvine, Calif)^{23,24} bioprostheses at 10 years. In total, 14 prostheses required explantation and all cases

are presented individually and in greatest detail elsewhere including full patient histories, post hoc analysis of the transesophageal echocardiography records, intraoperative findings, histologies as well as indications, morphologic, and technical details of reoperations.¹⁵ Prostheses with tears and cusp ruptures in our series were relatively easy to replace; however, cases with severe calcification turned out to require very difficult and demanding reoperations, confirming a previous report.²⁶ The freedom from SVD in our series was only 0.70 after 9 years, substantially lower than the rates of 0.86 to 0.97 reported for conventional stented valves at 10 years; that is, the Hancock II,^{22,23} Mosaic (Medtronic Inc, Minneapolis, Minn),²⁵ and Perimount Magna.²³

The morphologic and hemodynamic criteria defined in this study for SVD indicate intrinsic changes in the valve, suggesting at least moderate aortic stenosis associated with left ventricular hypertrophy,²⁷ substantial complications and event rates from aortic stenosis,²⁸ impaired event-free survival, and increased overall mortality.²⁹ Thus the definition for SVD in our study is rather conservative considering the generally larger EOA and lower gradients of stentless versus stented valves.

In general, SVD is influenced by the tissue structure (eg, bovine vs porcine), the design of the valve, as well as its mechanical wear and stress absorption properties. Notably, chemical fixation and the anticalcification treatment are considered key elements in valve manufacturing aimed at enhancing valve durability and avoiding premature calcification, SVD, and reoperation.³⁰ All biological tissue valves, including the Solo, primarily undergo chemical fixation with GA to provide mechanical stability at the

expense of susceptibility to calcification. In a unique treatment, Sorin uses HCA featuring strong electronegative sulfonic groups as postfixation treatment bonding to neutralize free toxic aldehyde groups in the Solo valve.³¹ In a subcutaneous rat model, GA-HCA-treated bovine pericardium showed less calcification than those treated with GA alone after explantation (14-84 days).³¹ The effectiveness has been questioned because this model ignores mechanical and dynamic stress or blood-surface contact.³² In fact, results from the subcutaneous rat model were the exact opposite of those from the blood contact and the pulsatile models, emphasizing the necessity of blood contact in preclinical valve testing.³² Furthermore, and perhaps even more important, stentless valve implantation techniques are generally more demanding, less reproducible and standardized, and more dependent on the surgeon's skill and experience. Importantly, the ideal concept of a stentless valve prosthesis assumes that it can replace and imitate a native valve, thus adopting nearly identical functional durability. However, this theoretical idea ignores that the stentless valve may not seat adequately in the native aortic root. In detail, correct sizing and perfectly symmetrical implantation to ensure low leaflet stress is only rarely obtained with heterogeneous strain and elongation, compression, shear, and torsional deformation for the 3 sinuses,¹ whereas the Solo is constructed perfectly symmetrical and thereby causes stress variations on the leaflets.¹ In the sheep model, the left and noncoronary sinuses were found to undergo clockwise torsion during the ejection phase, whereas the right sinus undergoes counterclockwise torsion.¹ This puts stress on the noncoronary commissure/right coronary commissure and could explain why tears were predominantly seen close to this particular location. Any malpositioning and asymmetry between the native anatomy and the stentless tissue valve may cause small distortions with eccentric regurgitation and increased chronic mechanical stress, potentially leading to fatigue over time and premature valve deterioration.³³ Given the large individual variability in root anatomy, particularly of the noncoronary sinus, which is usually larger than the left and right coronary sinuses (with a larger volume, increased height, width, leaflet size, and thickness),¹ symmetric implantation, and tension-free positioning can hardly be guaranteed. As a consequence, the observation of root anatomy, correct sizing, and symmetric implantation of the Solo must be given particular attention.

Limitations

At the time of introduction of the Solo stentless prosthesis, no prior experience was available, and surgeons were engaged in proctoring and teaching, which could have influenced patient selection and technical precision. This study was not designed to investigate the cause of Solo-associated postoperative thrombocytopenia or the structural cardiac changes; that is, the mass regression and

its influence on survival. With regard to long-term adverse events, not all causes of death could be clarified. However, it must be expected that SVD in some patients contributed to premature death, particularly because two-thirds of patients diagnosed with SVD did not undergo reoperation for various reasons, and concomitant procedures do not fully explain the difference in mortality between isolated and combined procedures. Thus, competing events may potentially have influenced the assessment of other aortic-valve-related adverse events. We combined all end points to evaluate overall successful AVR with the Solo stentless prosthesis; albeit at the cost of losing clinically relevant information. Because our data reports outcomes from a single institution, we caution a premature final conclusion regarding the Solo; additional data from other centers are warranted to help to determine long-term durability of the Solo prosthesis.

CONCLUSIONS

The Solo stentless valve is safe to implant and shows excellent hemodynamic performance as well as early and midterm results. There were 26 cases of SVD during the follow-up period. Multivariate Cox regression analysis identified only younger age as an independent predictor for SVD, but not renal dysfunction, diabetes, arterial hypertension, nor PPM as continuous variables. However, actuarial freedom from SVD and explantation decreased markedly after only 5 to 6 years and was only 70% and 82% at 9 years, implying that the Solo durability is lower than that of conventional stented prostheses in our institution.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: aortic valve, stentless, bioprosthesis, cardiac surgery, valve surgery

EDITORIAL COMMENTARY

Getting to the (aortic) root of the problem

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Aortic valve replacement remains a process in evolution, with the ideal substitute always seemingly on the horizon. In recent years, great energy and effort have been expended

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