Management of small aortic annulus in the era of sutureless valves: A comparative study among different biological options

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ABSTRACT

Objective: Aortic valve replacement (AVR) in patients with a small aortic annulus is a challenging problem. The objective of this study was to compare 4 surgical approaches in terms of hemodynamics and perioperative outcomes.

Methods: A retrospective single-center study included 351 consecutive patients with a small aortic annulus (≤ 21 mm) who underwent aortic valve surgery between January 2007 and December 2014. Surgical techniques included standard AVR in 259 (74%) patients, aortic root enlargement in 20 (6%), implantation of a stentless bioprosthesis in 23 (6%), and sutureless AVR in 49 (13%).

Results: Three hundred and eleven (89%) patients were female. The mean Logistic EuroSCORE II varied significantly among the groups and ranged from $6.5\% \pm 5.4\%$ in the standard AVR group to $9.2\% \pm 4.7\%$ in the stentless group. Early mortality occurred in 26 (7%) patients. Patients in the stentless group had the lowest aortic valve mean gradients on predischARGE transthoracic echocardiography (10.9 ± 6.2 mm Hg; $P < .001$). In the stented group, the Trifecta prosthesis displayed the lowest postoperative mean transaortic gradient (10.3 ± 3.6 ; $P < .001$) with no severe prosthesis-patient mismatch. Postoperative gradients of the sutureless group were comparable with stented prostheses.

Conclusions: In our study, stentless AVR and Trifecta bioprostheses had the best hemodynamic outcomes. The Perceval sutureless prosthesis provides reasonable hemodynamic performance and is a safe alternative. (J Thorac Cardiovasc Surg 2016;152:1019-28)

Postoperative TTE gradient distribution.

Central Message

Stentless and Trifecta prostheses give the best hemodynamics in cases of small aortic annulus. Sutureless valves are comparable with stented prostheses.

Perspective

Aortic valve replacement in patients with a small aortic annulus is a challenging problem. The present study draws attention to the hemodynamic performance of 4 management strategies (stented AVR, stentless AVR, sutureless AVR, and aortic root enlargement) that could be used in the context of a small aortic annulus (≤ 21 mm).

See Editorial Commentary page 1028.

Severe aortic stenosis is a lethal disease that requires mechanical relief of left ventricular outflow obstruction.¹ Aortic valve replacement (AVR) is the gold standard treatment for severe symptomatic aortic stenosis.² The aim of AVR is to decrease pressure and volume overload on the left ventricle, allowing for left ventricular mass regression. To achieve this goal, residual transvalvular gradients should be minimal. However, implantation of a small

aortic valve sometimes leads to high residual gradients, despite a normally functioning prosthesis. In addition, patients with a small aortic annulus, especially those with a large body surface area, are at higher risk of prosthesis-patient mismatch, which is associated with worse clinical outcomes and decreased survival.³

Conventional stented valves have a sewing ring that is partially positioned within the blood flow causing relative flow obstruction,⁴ especially in patients with a small aortic annulus. To decrease residual gradients and left ventricular

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Scanning this QR code will take you to a procedural video.

Abbreviations and Acronyms

AVR	= aortic valve replacement
CABG	= coronary artery bypass graft
CPB	= cardiopulmonary bypass
EOA	= effective orifice area
iEOA	= indexed effective orifice area
PPM	= permanent pace maker
TAVI	= transcatheter aortic valve implantation
TEE	= transesophageal echocardiography
TTE	= transthoracic echocardiography

outflow tract obstruction, several alternatives have been proposed, including aortic root enlargement and root replacement using a stentless bioprosthesis. However, the hemodynamic benefits of these approaches must be weighed against an increased surgical risk because of technical difficulty, prolonged periods of cardiopulmonary bypass (CPB), and myocardial ischemia.⁵ Recently, sutureless aortic bioprostheses have been proposed as a new solution to the problem of the small aortic annulus in elderly high-risk surgical patients.⁶

The purpose of this study was to compare the hemodynamic performance among the 4 management strategies (stented AVR, stentless AVR, sutureless AVR, and aortic root enlargement) in the context of a small aortic annulus (≤ 21 mm).

METHODS**Study Population**

Between January 2007 and December 2014, 1703 patients with aortic stenosis who underwent AVR with a biological substitute in our institution were identified. Patients who received a mechanical prosthesis or who underwent a Ross procedure were excluded. In our institution, these operations are performed mainly in younger patients (<60 years). These patients represent a distinct population from the cohort studied herein, as they tend to have a lower surgical risk, with a lower incidence of mortality and morbidity. A total of 351 consecutive patients with an aortic annulus of 21 mm or less were included. Among these, 259 (74%) underwent standard AVR with stented aortic prosthesis, 20 (6%) underwent aortic root enlargement, 23 (6%) underwent implantation of a stentless bioprosthesis, and 49 (13%) underwent sutureless AVR. The population flowchart is shown in Figure 1.

This observational, single-center, cohort study was approved by the local ethics committee and a waiver of consent was obtained.

Data Collection and Follow-up

Clinical data were prospectively collected in our center's Valve Clinic database. When necessary, individual chart review was performed to complete the dataset. Early postoperative outcomes were defined in accordance with the Society of Thoracic Surgeons' Guidelines for Reporting Mortality and Morbidity After Cardiac Valve Interventions.⁷ Operative mortality was defined as death occurring within 30 days of surgery or during the index hospitalization. Echocardiographic parameters including mean aortic gradient, peak aortic gradient, effective orifice area (EOA), and indexed EOA (iEOA) were assessed intraoperatively and before discharge. Eligibility for the study was determined on the basis of

the preoperative aortic annulus diameter as assessed on intraoperative transesophageal echocardiography (TEE). All measurements were carried out by a single blinded observer. All patients underwent a predischarge transthoracic echocardiography (TTE) at an average of 4 ± 2 days postoperatively. Moderate and severe prosthesis-patient mismatch was defined as an iEOA between 0.60 to 0.85 cm^2/m^2 and <0.60 cm^2/m^2 , respectively.³ Body surface area was calculated using DuBois's formula. Creatinine clearance was calculated using the Cockcroft-Gault formula.

Outcome Definition

The primary study endpoint was the hemodynamic performance of each approach (mean transaortic pressure gradients, peak transaortic pressure gradients, EOA, iEOA, and incidence of moderate or severe prosthesis-patient mismatch) in postoperative TEE and in TTE at discharge.

Secondary outcomes were early postoperative adverse events. A further analysis was done to compare hemodynamic performance of various stented bioprostheses and patients with aortic annulus <20 mm versus ≥ 20 mm.

Surgical Technique

All surgical procedures were performed by 8 attending surgeons at our institution. The choice of procedure was based on individual patient characteristics and surgeon/patient preference. Aortic root replacement or enlargement was preferred in young patients, especially those who had previously undergone AVR or aortic root surgery. Sutureless prostheses have been implanted in our center since 2011. Sutureless AVR was preferred in older patients (>70 years), patients with calcified aortic root or coronary ostia, and in patients undergoing minimally invasive AVR.

In the standard AVR group, the prosthesis was implanted using interrupted pledgetted mattress sutures. Both supra- and intraannular techniques were used according to the surgeon's preference. Sutureless AVR using the Perceval S prosthesis (Sorin Group, Saluggia, Italy) (Video 1) was performed using a specific delivery system. A catheter balloon was inserted and inflated to complete the prosthesis deployment. All patients undergoing stentless AVR received a complete root replacement. The same aortic root enlargement technique was performed in the 20 patients in this group as follows: the aortotomy incision is extended toward the posterior commissure between the noncoronary and the left coronary aortic cusps, passing through the aortic annulus, and carried 5 to 10 mm downwards where it stops at the anterior mitral leaflet annulus to avoid any postoperative impairment of mitral valve function. A patch of Dacron is then sutured to the V-shaped defect and the aortic prosthesis is implanted.

Statistical Analysis

Continuous variables are presented as means $\pm$ standard deviations and were compared using the Student *t* test or the Mann-Whitney *U* test, as appropriate. The Kruskal-Wallis test was used when more than 2 measurements were compared. Only available values were included in the analysis. Categorical variables are presented as frequency (%) and were compared using Pearson's χ^2 test when the expected frequency count for each contingency table's cell was at least 5. Otherwise, a Fisher exact test was used. Statistical significance was set at $\alpha \leq 0.05$. Postoperative aortic gradients and aortic valvular area data were missing in less than 1% of patients. Whenever a value for a given variable was unavailable, the patient was not included in the analysis to avoid any nonresponse bias. Statistical analyses were performed using Statistical Package for Social Sciences v20 (IBM, Armonk, NY).

RESULTS**Patients' Baseline Characteristics**

The patient's baseline characteristics are presented in Table 1. The mean age differed significantly among the

FIGURE 1. Population flow chart. AVR, Aortic valve replacement; AS, aortic stenosis.

groups; patients in the aortic root enlargement and stentless groups were younger. There was no statistically significant difference in age among patients undergoing stented or sutureless AVR. A total of 311 patients (89%) in this cohort were female. There was no significant difference in the mean body mass index. Mean creatinine clearance was significantly higher in the aortic root enlargement and stentless groups compared with the standard AVR and sutureless groups, with no difference between the latter 2 groups ($P = .48$). Endocarditis was the indication for surgery in 7 patients (2%). Four patients had acute endocarditis and the remaining 3 had healed endocarditis.

None of these patients had aortic root abscesses or aortic annulus involvement. A significantly higher proportion of patients in the stentless group (26%) had undergone previous cardiac surgery compared with patients in the aortic root enlargement (20%), sutureless (12%), or standard AVR (7%) groups ($P < .001$). In the stentless group, 6 patients (26%) had previous cardiac surgeries. Each of these patients had previous aortic valve surgery, 4 had isolated AVR, 1 had AVR plus coronary artery bypass graft (CABG), and 1 had AVR in addition to aortic root enlargement. The mean Logistic EuroSCORE II varied significantly among the groups and ranged from $6.5\% \pm 5.4\%$ in the standard AVR group to $9.2\% \pm 4.7\%$ in the stentless group.

Intraoperative Data

Intraoperative data are presented in Table 2. Fourteen patients from the sutureless group underwent surgery through a right anterior minithoracotomy and 3 through a hemisternotomy. All other patients received a full median sternotomy. Isolated AVR was performed in 157 patients (45%). Concomitant procedures included CABG, multiple valve procedure, septal myectomy, and Maze in 141 (40%), 35 (10%), 17 (5%), and 7 (2%) patients, respectively, with no statistically significant difference among the groups.

In the stented prostheses group, 19-mm and 21-mm prostheses were implanted in 156 (60%) and 103 (40%) patients, respectively. Fifty-eight (22%) received Carpentier-Edwards Perimount valves (Edwards Lifesciences, Irvine, Calif), 145 (56%) received Carpentier-Edwards Perimount Magna Ease valves (Edwards Lifesciences), 23 (9%)

VIDEO 1. Minimally invasive aortic valve replacement using the Perceval S sutureless prosthesis via right anterior mini thoracotomy. Video available at [http://www.jtcvsonline.org/article/S0022-5223\(16\)30851-0/addons](http://www.jtcvsonline.org/article/S0022-5223(16)30851-0/addons).

TABLE 1. Patient's baseline characteristics by procedure type

Variable	Stented (n = 259)	Aortic root enlargement (n = 20)	Stentless (n = 23)	Sutureless (n = 49)	P
Age, y $\pm$ SD	74.7 $\pm$ 7.6	69.9 $\pm$ 5.4	64.8 $\pm$ 11.6	78.0 $\pm$ 6.0	<.001
Female gender	229 (88)	16 (80)	18 (78)	48 (98)	.03
Body mass index, kg/m ² $\pm$ SD	28.3 $\pm$ 5.9	29.5 $\pm$ 6.8	29.4 $\pm$ 7.1	28.4 $\pm$ 7.1	.84
Body surface area, m ² $\pm$ SD	1.66 $\pm$ 0.16	1.64 $\pm$ 0.43	1.72 $\pm$ 0.20	1.62 $\pm$ 0.14	.23
Hypertension	213 (82)	13 (65)	19 (83)	44 (90)	.22
Dyslipidemia	188 (73)	10 (50)	14 (61)	44 (90)	.002
Diabetes	84 (32)	8 (40)	1 (4)	16 (33)	.03
Coronary artery disease	132 (51)	8 (40)	11 (48)	37 (75)	.009
Endocarditis	5 (2)	0 (0)	2 (9)	0 (0)	.16
Peripheral vascular disease	41 (16)	2 (10)	3 (13)	10 (20)	.60
COPD	41 (16)	3 (15)	7 (29)	12 (24)	.18
Chronic kidney disease	51 (20)	5 (25)	2 (9)	13 (26)	.30
Creatinine clearance, mL/min $\pm$ SD*	52.4 $\pm$ 19.3	62.7 $\pm$ 23.3	77.5 $\pm$ 27.3	50.1 $\pm$ 22.3	<.001
NYHA class $\geq$ III/IV	85 (33)	12 (60)	14 (61)	31 (63)	.32
LV ejection fraction, % $\pm$ SD	59.8 $\pm$ 9.3	61.5 $\pm$ 5.6	61.7 $\pm$ 6.7	59.4 $\pm$ 6.5	.62
Atrial fibrillation	38 (15)	1 (5)	2 (9)	9 (18)	.53
Permanent pacemaker	12 (5)	2 (10)	0 (0)	3 (6)	.36
Previous cardiac surgery	19 (7)	4 (20)	6 (26)	6 (12)	<.001
Previous aortic valve surgery	8 (3)	2 (10)	6 (26)	6 (12)	<.001
Logistic EuroSCORE II, % $\pm$ SD	6.5 $\pm$ 5.4	7.0 $\pm$ 10.2	9.2 $\pm$ 4.7	8.9 $\pm$ 8.9	.004

Values are number (%) unless indicated otherwise. SD, Standard deviation; COPD, chronic obstructive pulmonary disease; NYHA, New York Heart Association; LV, left ventricular. *Calculated using Cockcroft-Gault formula.

received Sorin Mitroflow valves (Sorin Group), and 33 (13%) received St Jude Medical Trifecta valves (St Jude Medical, Inc, St Paul, Minn).

In the aortic root enlargement group, 19-mm, 21-mm, and 23-mm prostheses were implanted in 7 (35%), 12 (60%), and 1 (5%) patients, respectively. The 7 patients who received a 19-mm prosthesis initially had a mean aortic annulus of 18 ± 0.6 mm that did not fit the 19-valve sizer before the aortic root enlargement. Four patients (20%) received Carpentier-Edwards Perimount valves, 15 (75%) received Carpentier-Edwards Perimount Magna Ease valves, and 1 (5%) received a Sorin Mitroflow valve.

In the stentless group, 19-mm, 21-mm, 23-mm, and 25-mm Freestyle prostheses (Medtronic, Inc, Minneapolis, Minn) were implanted in 1 (4%), 9 (39%), 12 (53%), and 1 (4%) patients, respectively. All patients in the sutureless group had a Perceval S prosthesis (Sorin Group). Forty-seven (96%) patients received small (19-21 mm) valves and 2 (4%) received medium (21-23 mm) valves.

CPB and aortic cross-clamp times were significantly shorter in the sutureless group for both isolated AVR and combined procedures. Intraoperative blood loss was also significantly lower in the sutureless group for both isolated AVR and combined procedures.

Perioperative Outcomes

Clinical outcomes are presented in Table 3. Overall early mortality occurred in 26 (7%) patients (3% in the isolated AVR group and 11% in the combined and redo procedures group). There was a higher incidence of permanent pace

maker (PPM) implantation in the sutureless group (20%; $P = .005$). In the redo and concomitant procedure group, the incidence of postoperative PPM implantation was significantly higher in the stentless group ($P = .008$). All PPM implantation in the stentless group occurred with redo procedures. Overall, there was no difference in bleeding requiring reintervention. In the isolated AVR group, there was a higher incidence of reoperation for bleeding (33%; $P = .03$).

Hemodynamic Data

Hemodynamic parameters measured preoperatively, intraoperatively, and before discharge are presented in Table 4. There were no differences in preoperative transaortic gradients and aortic valve area among the various groups. Mean aortic annulus diameter, as assessed by intraoperative TEE before incision, was comparable among the groups. However, there was a statistically significant difference in indexed aortic annulus diameter, which ranged between 10.2 ± 3.8 mm/m² in the aortic root enlargement group and 12.1 ± 1.3 mm/m² in the sutureless group ($P = .02$).

Upon CPB weaning, there was a statistically significant difference in mean transaortic gradients, with the lowest gradients being observed in the stentless group (8.2 ± 5.2 mm Hg) (Table 4). There was no case of moderate-to-severe paravalvular leak in this cohort and no statistically significant difference in the incidence of mild paravalvular leak among the various groups.

TABLE 2. Intraoperative data

Variable	Stented (n = 259)	Aortic root enlargement (n = 20)	Stentless (n = 23)	Sutureless (n = 49)	P
Isolated AVR, n (%)	119 (46)	9 (46)	9 (61)	20 (47)	.85
Concomitant procedures, n (%) [*]					
CABG	106 (38)	9 (42)	6 (26)	20 (41)	.54
Multiple valve procedure	25 (11)	1 (4)	2 (9)	7 (14)	.70
Septal myectomy	12 (5)	0 (0)	3 (13)	2 (4)	.28
Maze	6 (2)	0 (0)	0 (0)	1 (2)	>.99
Cross-clamp time, min ± SD [†]					
Isolated	63.7 ± 23.3	90.7 ± 27.3	88.9 ± 21.4	45.9 ± 20.1	<.001
Combined/redo procedure	87.7 ± 35.5	85.9 ± 27.9	131.6 ± 33.0	67.7 ± 31.3	<.001
CPB time, min ± SD [†]					
Isolated	81.2 ± 29.6	114.1 ± 30.4	132.7 ± 56.7	64.1 ± 29.3	<.001
Combined/redo procedure	110.0 ± 43.2	106.5 ± 35.2	178.8 ± 36.8	85.2 ± 37.4	<.001
Blood loss, mL ± SD [†]					<.001
Isolated	425.2 ± 322.6	685.6 ± 458.9	475.0 ± 128.2	278.8 ± 192.5	.002
Combined/redo procedure	464.6 ± 274.9	868.8 ± 891.6	137.5 ± 783.2	298.9 ± 147.9	<.001

AVR, Aortic valve replacement; CABG, coronary artery bypass graft; SD, standard deviation; CPB, cardiopulmonary bypass. ^{*}Categories are not mutually exclusive. [†]Excluding redo procedures.

Distribution of predischARGE TTE transaortic gradients is presented [Figure 2](#). On predischARGE TTE evaluation, there was a statistically significant difference in mean transaortic gradients ($P < .001$) and in aortic iEOA ($P < .001$). The lowest gradients were in the stentless group (10.9 ± 6.2 mm Hg) and the highest gradients were in the standard AVR group (18.7 ± 8.5 mm Hg). Similarly, the largest aortic iEOA was in the stentless group (1.1 ± 0.4 cm²/m²) and the smallest was in the sutureless group (0.79 ± 0.20 cm²/m²). No moderate-to-severe paravalvular leak was observed and there was no statistically significant difference in the incidence of mild paravalvular leak. The overall incidence of moderate and severe prosthesis-patient mismatch was 25% and 14%, respectively, with no statistically significant difference among the groups.

The hemodynamic performance of the various types of stented bioprostheses is summarized in [Table 5](#). The mean body surface area was 1.66 ± 0.15 m² in the Perimount group, 1.66 ± 0.18 m² in the Magna Ease group, 1.66 ± 0.15 m² in the Mitroflow group, and 1.66 ± 0.13 m² in the Trifecta group ($P > .99$). When compared with the other bioprostheses, the Trifecta had lower mean transaortic gradients (10.3 ± 3.6 mm Hg; $P < .001$), larger iEOA (1.00 ± 0.22 cm²/m²; $P < .001$), and a lower incidence of severe prosthesis-patient mismatch (0%; $P = .01$).

Dividing the cohort into 2 subgroups of patients with aortic annulus <20 mm and ≥ 20 mm displayed similar results, with the lowest gradients in the stentless groups (10.4 ± 6.0 mm Hg and 11.6 ± 6.9 mm Hg, respectively).

DISCUSSION

AVR in the context of small aortic annulus is a challenge because residual transaortic gradients and prosthesis-patient

mismatch can result in worse clinical outcomes and decreased survival.³ The present study is the first to compare contemporary strategies (stented AVR, stentless AVR, sutureless AVR, and AVR with aortic root enlargement) in the management of patients with small aortic annulus ([Figure 3](#)).

Stented AVR

Most patients requiring surgery for aortic stenosis underwent standard stented AVR, because this intervention is straightforward and provides reproducible safe results. In this cohort, patients who received a stented prosthesis displayed the highest residual gradients. Furthermore, 39% of the patients in the standard AVR group had a postoperative iEOA of 0.85 cm²/m² or less. These results are in accordance with the fact that bioprostheses tend to leave supra-physiologic transvalvular systolic gradients.⁸ This could have major long-term impact as several published studies have linked prosthesis-patient mismatch to worse postoperative outcomes in patients undergoing AVR, with less symptomatic relief, less left ventricular mass regression, and higher early and late mortality.³

The Trifecta bioprostheses displayed the lowest mean aortic gradient compared with other stented prosthesis (7.1 mm Hg) and no severe prosthesis-patient mismatch. This is consistent with other recently published studies in which the Trifecta prosthesis showed near physiologic hemodynamics that mirror the stentless prosthesis.^{9,10} There are no long-term durability data available for the newly introduced Trifecta prosthesis. A few cases of early structural deterioration of the Trifecta prosthesis have been reported in the literature.^{11,12} Although this did not discourage the implantation of this valve in our center,

TABLE 3. Clinical outcomes

Variable	Aortic root				P
	Stented (n = 259)	enlargement (n = 20)	Stentless (n = 23)	Sutureless (n = 49)	
Early mortality	14 (5)	4 (20)	3 (13)	5 (10)	.06
Isolated AVR	2 (2)	1 (11)	2 (22)	0 (0)	.02
Combined/redo procedure	12 (9)	3 (27)	1 (7)	5 (17)	.10
Bleeding requiring reoperation	21 (8)	4 (20)	1 (4)	3 (6)	.27
Isolated AVR	6 (5)	3 (33)	1 (11)	1 (5)	.03
Combined/redo procedure	15 (11)	1 (9)	0 (0)	2 (7)	.68
Stroke	15 (6)	1 (5)	1 (4)	3 (6)	>.99
Isolated AVR	5 (4)	0 (0)	0 (0)	0 (0)	>.99
Combined/redo procedure	10 (7)	1 (9)	1 (7)	3 (10)	.86
Acute kidney injury*	89 (34)	7 (35)	12 (52)	17 (35)	.41
Isolated AVR	42 (35)	3 (33)	5 (55)	7 (35)	.66
Combined/redo procedure	47 (34)	4 (36)	7 (50)	10 (34)	.69
Renal replacement therapy	13 (5)	1 (5)	1 (4)	4 (8)	.90
Isolated AVR	6 (5)	1 (11)	0 (0)	0 (0)	.45
Combined/redo procedure	7 (5)	0 (0)	1 (7)	4 (14)	.27
Permanent pacemaker implantation	17 (7)	0 (0)	4 (17)	10 (20)	.005
Isolated AVR	7 (6)	0 (0)	0 (0)	3 (15)	.37
Combined/redo procedure	10 (7)	0 (0)	4 (29)	7 (24)	.008
Hospital stay, d $\pm$ SD†	10.0 $\pm$ 7.8	14.5 $\pm$ 26.3	8.5 $\pm$ 4.0	12.3 $\pm$ 9.3	.1
Isolated AVR	9.5 $\pm$ 7.2	16.8 $\pm$ 25.4	7.3 $\pm$ 4.5	13.4 $\pm$ 10.3	.04
Combined/redo procedure	10.6 $\pm$ 10.5	9.7 $\pm$ 4.6	7.6 $\pm$ 4.5	11.5 $\pm$ 9.4	.86

Values are number (%) unless indicated otherwise. AVR, Aortic valve replacement; SD, standard deviation. *Defined as an increase in serum creatinine >50% from baseline.

†Calculated for perioperative survivors only.

further studies with longer follow-up are needed to evaluate its durability. We believe that the Trifecta prosthesis is a rational option for elderly patients with a small aortic annulus who undergo stented AVR.

Aortic Root Enlargement Technique

Aortic root enlargement has been proposed as an alternative to standard AVR in patients with a small aortic annulus.¹³ The purpose of this procedure is to allow for the implantation of a larger prosthesis. In this group, patients who received a 19-mm stented prosthesis initially had a very small aortic annulus (mean of 18 mm) that did not fit the 19-valve sizer before the aortic root enlargement. This could explain the fact that the hemodynamic performance granted by the aortic root enlargement was only slightly superior to that obtained with standard AVR and significantly inferior to that observed in the stentless group. Furthermore, the operative mortality and the incidence of reintervention for bleeding in the aortic root enlargement group was relatively high. According to these results, the role of aortic root enlargement in the management of small aortic annulus remains limited.

Stentless AVR

Our study suggests that stentless and Trifecta prostheses have the best hemodynamic performance in terms of postoperative transaortic gradients and iEOA. The advantage of complete aortic root replacement is the

capacity to oversize the prosthesis in relation to the patient's aortic annulus. In our study, most patients (57%) received a 23-mm or larger prosthesis. Two randomized trials have demonstrated lower gradients than stented bioprosthesis in patients with a small aortic annulus.^{14,15} The use of this prosthesis is also associated with left ventricular mass regression and a more complete resolution of left ventricular hypertrophy compared with stented valves.¹⁴ Recent reports have demonstrated good durability up to 15 years after implantation and superior midterm survival when compared with the stented prosthesis.^{16,17}

This procedure is technically more complex, requiring advanced experience in aortic surgery, and results in a longer operative time, raising questions about its widespread applicability.¹⁸ The operative mortality in the stentless group was relatively high. The stentless AVR cohort being small, any conclusion on increased operative mortality remains speculative. However, previous reports raised the potential of increased adverse perioperative outcomes^{19,20} with the use of stentless AVR. Furthermore, the high PPM implantation rate in patients undergoing stentless AVR has been described by other groups^{21,22} and may be, at least in our study, partly explained by the high proportion of patients in this group undergoing redo surgery. The implantation of a stentless bioprosthesis should be considered in low-risk, relatively younger patients undergoing AVR because it provides the best hemodynamic performance.

TABLE 4. Hemodynamic parameters

Variable	Stented (n = 259)	Aortic root enlargement (n = 20)	Stentless (n = 23)	Sutureless (n = 49)	P
Preoperative TTE					
Peak transaortic gradient, mm Hg	77.5 ± 32.3	61.4 ± 22.9	84.3 ± 32.9	77.2 ± 30.5	.22
Mean transaortic gradient, mm Hg	48.9 ± 20.6	44.1 ± 18.6	51.9 ± 23.5	46.8 ± 20.1	.60
AVA, cm ²	0.74 ± 0.25	0.80 ± 0.21	0.76 ± 0.32	0.74 ± 0.22	.82
Indexed AVA, cm ² /m ²	0.40 ± 0.20	0.42 ± 0.19	0.44 ± 0.21	0.45 ± 0.16	.45
Intraoperative TEE before CPB					
Annulus diameter, mm	19.7 ± 1.2	19.1 ± 1.7	19.0 ± 1.7	19.5 ± 1.3	.10
Indexed annulus diameter, mm/m ²	11.5 ± 2.4	10.2 ± 3.8	11.2 ± 1.5	12.1 ± 1.3	.02
Intraoperative TEE after CPB weaning					
Mean transaortic gradient, mm Hg	11.1 ± 6.8	10.5 ± 6.2	8.2 ± 5.2	9.0 ± 4.4	.04
Paravalvular leak, n (%)					
None	247 (95)	20 (100)	23 (100)	45 (92)	.44
Trivial-mild	12 (5)	0 (0)	0 (0)	4 (8)	
Moderate-severe	0 (0)	0 (0)	0 (0)	0 (0)	
PredischARGE TTE					
Peak transaortic gradient, mm Hg	33.6 ± 14.7	29.4 ± 14.5	20.3 ± 10.4	29.8 ± 9.7	<.001
Mean transaortic gradient, mm Hg	18.7 ± 8.5	16.2 ± 7.3	10.9 ± 6.2	17.3 ± 6.7	<.001
Mean transaortic gradient per indexed annulus diameter, mm Hg/mm/m ²	1.6 ± 0.7	1.5 ± 0.8	1.0 ± 0.6	1.5 ± 0.6	.004
EOA, cm ²	1.42 ± 0.38	1.61 ± 0.47	1.82 ± 0.53	1.26 ± 0.27	.001
Indexed EOA, cm ² /m ²	0.82 ± 0.24	0.86 ± 0.37	1.10 ± 0.36	0.79 ± 0.20	.01
Paravalvular leak, n (%)					
None	241 (93)	19 (95)	22 (96)	40 (82)	.08
Trivial-mild	18 (7)	1 (5)	1 (4)	9 (18)	
Moderate-severe	0 (0)	0 (0)	0 (0)	0 (0)	
Severe PP mismatch*	37 (14)	1 (5)	2 (9)	10 (20)	.38
Moderate PP mismatch†	63 (24)	6 (30)	4 (17)	14 (29)	.71

Continuous variables are presented as means ± standard deviation. TTE, Transthoracic echocardiogram; AVA, aortic valve area; TEE, transesophageal echocardiogram; CPB, cardiopulmonary bypass; EOA, effective orifice area; PP, prosthesis-patient. *Defined as an indexed aortic effective orifice area <0.60 cm²/m². †Defined as an indexed aortic effective orifice area between 0.60 and 0.85 cm²/m².

Sutureless Bioprosthesis

In our study, sutureless AVR displays similar hemodynamic performance to standard AVR in the context of small aortic annulus. In a recently published multicenter propensity-matched analysis, D’Onofrio and colleagues²³ suggested that sutureless AVR compares favorably with

standard AVR and transcatheter aortic valve implantation (TAVI) in terms of perioperative outcomes and early postoperative gradients. In addition, Shrestha and colleagues⁶ compared hemodynamic performance of sutureless and stented prosthesis in the context of small aortic annulus (<22 mm). There was no difference in terms of postoperative gradients and EOA. The mean transaortic gradient in the sutureless group was close to our sutureless cohort (15.9 mm Hg). In contrast, in a multicenter study, Villa and colleagues²⁴ compared 276 patients who underwent sutureless AVR with the Perceval S prosthesis with a small versus a large prosthesis. There was no difference in terms of postoperative gradients suggesting that sutureless AVR in the context of small aortic annulus could result in comparable hemodynamic performance in both small and large aortic annulus. Sutureless AVR in patients with small aortic annulus is safe in terms of early postoperative hemodynamic results. Although postoperative paravalvular leakage remains an important concern for surgeons while using sutureless valves, there were no patients with moderate or severe paravalvular leakage at discharge in this study.

FIGURE 2. Box-and-whiskers graph of postoperative mean gradients by procedure type, assessed with transthoracic echocardiography. Vertical line represents the median. Left and right extremities of each box represent the first and third quartiles, respectively. The whiskers extend to the lowest and highest observations. MAG, Mean aortic gradient.

TABLE 5. Hemodynamic parameters in stented prosthesis

Variable	Perimount (n = 58)	Magna Ease (n = 145)	Mitroflow (n = 23)	Trifecta (n = 33)	P
Intraoperative TEE before CPB					
Annulus diameter, mm $\pm$ SD	19.7 $\pm$ 1.4	19.7 $\pm$ 1.2	19.2 $\pm$ 1.3	19.7 $\pm$ 1.2	.23
Indexed annulus diameter, mm/m ² $\pm$ SD	10.9 $\pm$ 3.2	11.7 $\pm$ 2.5	11.5 $\pm$ 1.2	11.7 $\pm$ 1.1	.17
Intraoperative TEE after CPB weaning					
Mean transaortic gradient (mm Hg)	13.2 $\pm$ 7.9	11.3 $\pm$ 6.9	12.0 $\pm$ 6.1	7.1 $\pm$ 3.3	.001
PredischARGE TTE					
Peak transaortic gradient, mm Hg $\pm$ SD	41.6 $\pm$ 18.2	35.3 $\pm$ 11.4	41.4 $\pm$ 14.4	17.9 $\pm$ 6.1	<.001
Mean transaortic gradient, mm Hg $\pm$ SD	22.3 $\pm$ 8.0	19.9 $\pm$ 8.5	19.4 $\pm$ 8.1	10.3 $\pm$ 3.6	<.001
EOA, cm ² $\pm$ SD	1.20 $\pm$ 0.34	1.34 $\pm$ 0.35	1.22 $\pm$ 0.49	1.62 $\pm$ 0.37	<.001
Indexed EOA, cm ² /m ² $\pm$ SD	0.73 $\pm$ 0.21	0.81 $\pm$ 0.23	0.74 $\pm$ 0.31	1.00 $\pm$ 0.22	<.001
Severe PP mismatch, n (%) [*]	7 (12)	23 (16)	6 (26)	0 (0)	.01
Moderate PP mismatch, n (%) [†]	14 (24)	34 (23)	2 (9)	9 (27)	.36

TEE, Transesophageal echocardiogram; CPB, cardiopulmonary bypass; SD, standard deviation; TTE, transthoracic echocardiogram; EOA, effective orifice area; PP, prosthesis-patient. ^{*}Defined as an indexed aortic effective orifice area <0.60 cm²/m². [†]Defined as an indexed aortic effective orifice area between 0.60 and 0.85 cm²/m².

Despite patients in the sutureless group being older and presenting a higher logistic EuroSCORE, no excess operative mortality was observed. However, patients in this group had the highest rate of atrioventricular block

(30%) and PPM implantation (20%). Due to the absence of a sewing ring, the Perceval S prosthesis relies on radial forces for stability, raising concerns that this may cause compression of the conduction system. This mechanism

FIGURE 3. Proposed algorithm for management of small aortic annulus. *TAVI (transcatheter aortic valve implantation) was not assessed by the present study. STS, Society of Thoracic Surgeons; AVR, aortic valve replacement.

could explain the increased incidence of conduction abnormalities in these patients. The long hospital stay observed in the sutureless AVR group can be explained by the high rate of pacemaker implantation in this group, an intervention that generally necessitates additional hospitalization days.

Although there was no statistically significant difference in the incidence of severe prosthesis-patient mismatch among the 4 groups ($P = .38$), there was a trend toward higher rates in the sutureless group. One of the specificities of sutureless AVR is that surgeons are not obliged to totally decalcify the aortic annulus after excision of the diseased aortic cusps. In our center, patients with severe calcification of the aortic annulus and/or the aortic root underwent the minimum necessary decalcification of the aortic annulus followed by deployment of the sutureless aortic valve. We think that this might partly explain the high incidence of prosthesis-patient mismatch in this group. Nonetheless, this hypothesis remains entirely speculative and is not based on any hard evidence.

Study Limitations

The main limitations of this study include its retrospective nature, lack of follow-up data, and the relatively small number of patients in the aortic root enlargement and stentless groups in comparison with the standard stented AVR and sutureless groups. Thus, the study sample size limits the conclusions that can be drawn from the present study. In addition, early complications in each group should be interpreted with caution because the observed differences could be due to differences in the baseline characteristics of the populations, which cannot be fully accounted for. Furthermore, the choice of procedure was sometimes dictated by anatomic limitations. For example, in the setting of a calcified aortic root and/or calcified coronary buttons, aortic root enlargement or aortic root replacement were seldom performed. In such a context, we favored simpler operations such as stented bioprosthetic AVR or sutureless AVR. Nonetheless, this is the first study to compare these 4 techniques and provides valuable hemodynamic information that adds to the current body of literature in the management of the small aortic annulus. Our study did not include patients who underwent TAVI. Percutaneous options represent an interesting alternative to surgical AVR in intermediate and high-risk patients, especially in the setting of a small aortic annulus.²⁵ Further studies are required to evaluate the hemodynamic performance of TAVI in this context compared with the 4 surgical strategies reported in the present study.

CONCLUSIONS

Management of the small aortic annulus should be tailored. Stentless and Trifecta prostheses seem to produce the best hemodynamic outcomes. However, stentless prostheses were associated with longer CPB times,

relatively higher early mortality, and perioperative morbidity. In our cohort, the remaining 3 options provided similar hemodynamic performance with relatively better perioperative outcomes. The most recent device, the Perceval sutureless prosthesis, is a safe alternative with a hemodynamic performance that appears to be in the same range as stented valves and aortic root enlargement procedures. Further studies are needed to compare the long-term durability of these techniques and to ascertain that superior perioperative hemodynamic performance improves long-term clinical outcomes.

Conflict of Interest Statement

Denis Bouchard discloses that he has received proctorship and lecturer fees from Sorin and Edwards Canada. Philippe Demers discloses that he has received proctorship from Sorin Canada. All other authors have nothing to disclose with regard to commercial support.

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Key Words: aortic valve replacement, aortic annulus, stentless prostheses, sutureless prostheses, prosthesis-patient mismatch

EDITORIAL COMMENTARY

Every millimeter counts

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We enjoyed reading the article Ghoneim and colleagues¹ in this issue of the *Journal*, “Management of Small Aortic Annulus in the Era of Sutureless Valves: A Comparative Study Between Different Biological Options,” because it addresses important issues of our daily praxis. Ghoneim and colleagues¹ investigated different biologic substitutes in small aortic annuli and found that the Trifecta (St Jude Medical, Inc, St Paul, Minn) and stentless valves provided the most effective relieve of aortic stenosis. Although there is a lot of bias in comparing the different groups, the results reflect real-life conditions, showing pressure gradients that are much higher than normal. Because bioprostheses are implanted more and more in younger patients, a pressure gradient as low as possible is important not only for survival but also for degeneration of the tissue.^{2,3} The annulus after decalcification is the implantation area to start with. The use of this plane determines the efficiency of surgery and the

bioprosthesis. Ideally, the minimal geometric orifice area of the substitute should be the same size as the implantation area. For example, a given aortic annular diameter of 20 mm means an area of 3.14 cm². If the achieved geometric orifice area of the substitute is only 18 mm (1 mm at each side for mounting device), the geometric orifice area would be 2.54 cm², which is nearly

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Central Message

Bioprostheses in small annuli have high pressure gradients. Efforts must focus on further reducing these gradients to approach normal conditions.

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