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Surgical Enlargement of the Aortic Root Does Not Increase the Operative Risk of Aortic Valve Replacement

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BACKGROUND: Surgical aortic root enlargement (ARE) during aortic valve replacement (AVR) allows for larger prosthesis implantation and may be an important adjunct to surgical AVR in the transcatheter valve-in-valve era. The incremental operative risk of adding ARE to AVR has not been established. We aimed to evaluate the early outcomes of patients undergoing AVR with or without ARE.

METHODS: From January 1990 to August 2014, 7039 patients underwent AVR (AVR+ARE, n=1854; AVR, n=5185) at a single institution. Patients with aortic dissection and active endocarditis were excluded. Mean age was 65±14 years and 63% were male. Logistic regression and propensity score matching were used to adjust for unbalanced variables in group comparisons.

RESULTS: Patients undergoing AVR+ARE were more likely to be female (46% versus 34%, *P*<0.001) and had higher rates of previous cardiac surgery (18% versus 12%, *P*<0.001), chronic obstructive pulmonary disease (5% versus 3%, *P*=0.004), urgent/emergent status (6% versus 4%, *P*=0.01), and worse New York Heart Association status (*P*<0.001). Most patients received bioprosthetic valves (AVR+ARE: 73.4% versus AVR: 73.3%, *P*=0.98) and also underwent concomitant cardiac procedures (AVR+ARE: 68% versus AVR: 67%, *P*=0.31). Mean prosthesis size implanted was slightly smaller in patients requiring AVR+ARE versus AVR (23.4±2.1 versus 24.1±2.3, *P*<0.001). In-hospital mortality was higher after AVR+ARE (4.3% versus 3.0%, *P*=0.008), although when the cohort was restricted to patients undergoing isolated aortic valve replacement with or without root enlargement, mortality was not statistically different (AVR+ARE: 1.7% versus AVR: 1.1%, *P*=0.29). After adjustment for baseline characteristics, AVR+ARE was not associated with an increased risk of in-hospital mortality when compared with AVR (odds ratio, 1.03; 95% confidence interval, 0.75–1.41; *P*=0.85). Furthermore, AVR+ARE was not associated with an increased risk of postoperative adverse events. Results were similar if propensity matching was used instead of multivariable adjustments for baseline characteristics.

CONCLUSIONS: In the largest analysis to date, ARE was not associated with increased risk of mortality or adverse events. Surgical ARE is a safe adjunct to AVR in the modern era.

Key Words: aortic valve replacement ■ outcome ■ propensity score ■ surgery

Sources of Funding, see page 1593

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Clinical Perspective

What Is New?

- This is the first large-scale study that examines the incremental risk of surgical aortic root enlargement in patients undergoing aortic valve replacement.
- We observed no incremental risk in postoperative mortality or adverse events after surgical enlargement of the aortic root compared with aortic valve replacement alone.

What Are the Clinical Implications?

- Patients with a small aortic annulus at risk for patient-prosthesis mismatch and those who may require transcatheter redo aortic valve replacement in the future may benefit from surgical enlargement of the aortic root.
- Surgical aortic root enlargement is a safe adjunct in the modern era and should be considered at the time of surgical aortic valve replacement.

There has been a dramatic increase in the use of bioprosthetic valves in patients undergoing aortic valve replacement (AVR), with this valve type accounting for ≈80% of all implanted prostheses in the recent years.[1,2] The major benefit of bioprosthetic valves is the avoidance of long-term anticoagulation, which leads to a lower cumulative risk of bleeding and thromboembolic events. Their Achilles' heel remains the anticipated structural valve deterioration, particularly in younger patients who may require multiple reinterventions.[3] With the advent of transcatheter aortic valve replacement (TAVR), failing prosthetic aortic valves are often replaced percutaneously, with a valve-in-valve (VIV) approach.[4,5] However, long-term durability of VIV TAVR remains unknown, and poor early outcomes have been reported, particularly in cases of small bioprosthetic valves at risk for patient-prosthesis mismatch (PPM).[4,6]

PPM after AVR increases all-cause and cardiac-related long-term mortality.[7–9] An adequate prosthetic valve size should match patients' body size to allow proper blood flow and promote left ventricular mass regression.[10,11] Pibarot et al[12,13] proposed a classification of PPM severity according to the valve's effective orifice area indexed by patients' body surface area (BSA), with severe PPM categorized as an indexed effective orifice area (EOAi) <0.65 cm^2/m^2. Several groups have reported that an EOAi <0.85 cm^2/m^2 is associated with worse hemodynamic and clinical outcomes after AVR.[14,15]

Surgical aortic root enlargement (ARE) during AVR allows for larger prosthesis implantation, thus minimizing PPM.[10,11,16–18] Furthermore, ARE may also benefit individuals who undergo a VIV TAVR in the future by allowing deployment of a larger percutaneous valve. Despite these potential benefits, surgical ARE has not been widely adopted by cardiac surgeons, likely because of concerns regarding the possible increased risk of early mortality and morbidity. Small single-center studies have reported acceptable results in patients undergoing aortic root enlargement at the time of AVR.[19–23] However, there is a paucity of data comparing early outcomes between AVR+ARE and AVR alone. We therefore conducted a retrospective cohort study with the objective of comparing early outcomes and determining the incremental risk of adding aortic root enlargement to AVR.

METHODS

Data Sources and Study Outcomes

This observational, single-center, cohort study was approved by the Review Ethics Board of University Health Network (Toronto, Ontario, Canada), and a waiver of consent was obtained. Patient-level data will not be made available to other researchers for the purposes of reproducing the results of this study because of privacy concerns. However, analytical methods and aggregate data are reported in the manuscript and the online-only Data Supplement. Perioperative clinical data were prospectively collected on all patients undergoing cardiac surgery in our institutional database. The primary outcome of this study was in-hospital mortality. Secondary outcomes of interest included postoperative adverse events, including acute myocardial infarction, low cardiac output, permanent pacemaker implantation, infection, atrial fibrillation, transient ischemic attack/stroke, reoperation for bleeding, and renal failure. All outcomes of interest were reported according to the American Association for Thoracic Surgery Guidelines for Reporting Mortality and Morbidity Mortality After Cardiac Valve Interventions.[24]

Study Population

All patients who underwent aortic valve replacement at the Toronto General Hospital, Peter Munk Cardiac Center from January 1990 to August 2014 were identified through the cardiovascular surgical database. Patients who underwent aortic valve replacement were included in the AVR group, and those who underwent AVR with a root enlargement were included in the AVR+ARE group. Operative reports were manually reviewed to confirm the technique of aortic root enlargement in the AVR+ARE group. Patients in the AVR+ARE group included all patients who had any form of aortic root or annular enlargement, including: (1) aortic root enlargement with replacement of the noncoronary sinus with a patch allowing for supraannular implantation of the valve (Figure 1), and (2) aortic annular enlargement with either the Nicks or Manouguian techniques or their modifications (Figure 2). The classical Nicks technique[25] (Figure 2B), which extends the aortotomy through the nadir of the noncoronary sinus to the aortic annulus, has been used regularly by our surgeons. We also regularly use the Nunez modification of the Manouguian technique[26] (Figure 2A). This technique extends the aortotomy through the commissure between the noncoronary and left cusps (the same direction as in the original Manouguian technique) to just above the confluence of the interventricular fibrous trigone, left atrial wall, and mitral valve

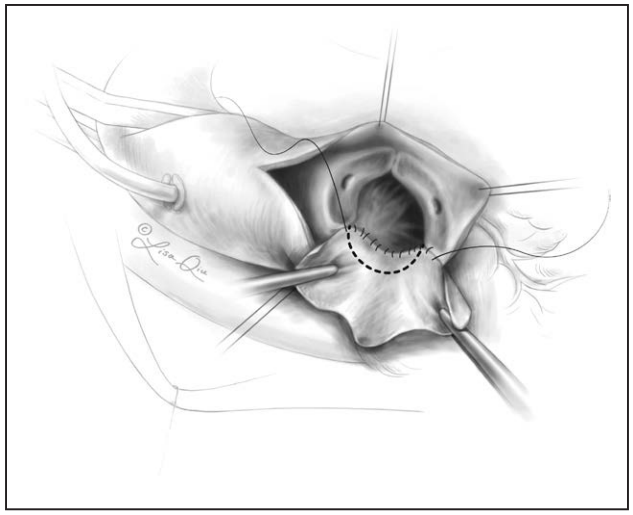

Figure 1. Surgical aortic root enlargement with replacement of the noncoronary sinus.
Note the supraannular placement of the aortic valve sutures as indicated by the dotted line across the patch. Reprinted with permission. © 2017 Lisa Qiu.

annulus, thus avoiding injury to the mitral leaflet and reconstruction of the left atrial roof. We reserve the original Manouguian technique,[27] which includes opening the left atrial roof and incising the anterior leaflet of the mitral valve, for patients requiring mitral valve replacement or extensive reconstruction of the base of the heart. Twenty-two surgeons performed aortic root enlargement during the study period, and the decision to enlarge the root and the choice of technique were most often dictated by personal experience and preference for one technique over another. Certain patient and anatomic factors, such as how small the baseline annulus was and what degree of enlargement was necessary for a given patient, were also taken into consideration. Patients with aortic dissection and active endocarditis, and those undergoing a composite valve graft procedure or Ross procedure, were excluded from this study.

Statistical Analysis

Categorical variables were reported as frequencies, and continuous variables were reported as mean±standard deviation or median with interquartile ranges as appropriate. Patient and surgical characteristics were compared using unpaired *t* test, analysis of variance test (continuous variables), or χ^2 tests (categorical variables) as appropriate. BSA was calculated based on the patient's weight (kg) and height (m) using the formula: BSA (m^2)=0.20247xheight $(m)^{0.725}$xweight $(kg)^{0.425}$. EOAi was calculated by determining the patient's implanted valve EOA (cm) as reported by Pibarot et al[13] and BSA (EOAi=EOA/BSA [cm/m^2]).

Logistic regression was used to examine the association of ARE with in-hospital mortality and adverse events. Risk factor analysis was conducted using backward selection using the Akaike Information Criterion.[28] Separate models were considered for each primary and secondary outcome. Although all other clinical characteristics were subject to variable selection,

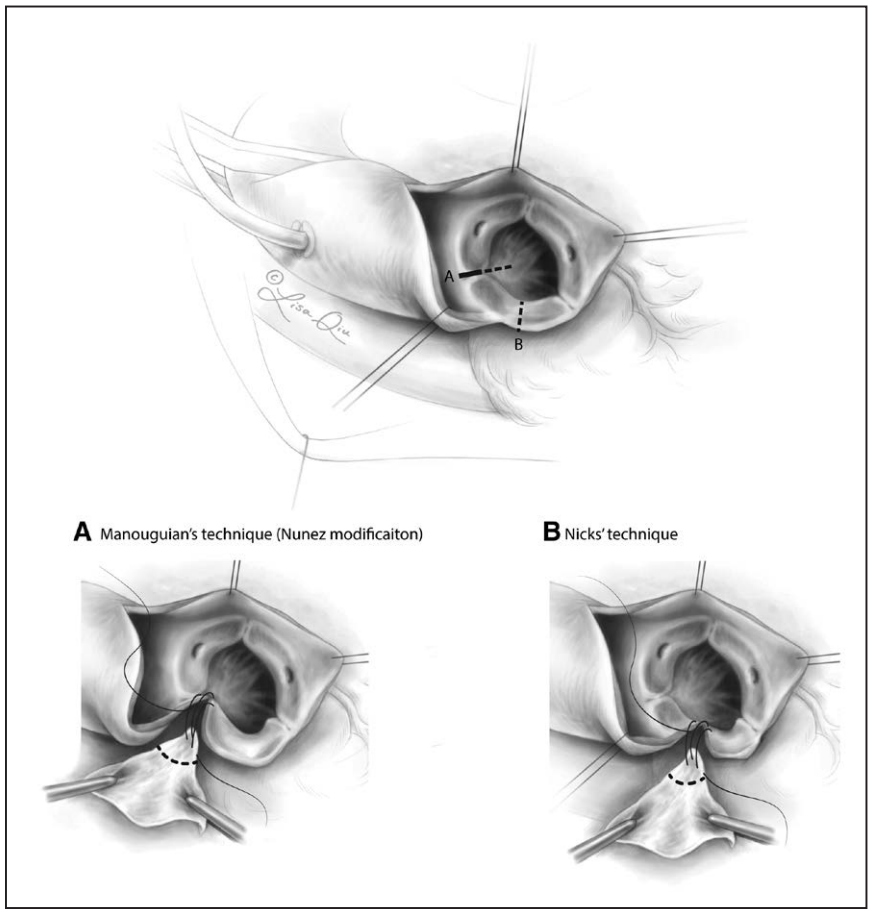

Figure 2. Aortic annular enlargement.
The solid line A represents the incision for the Nunez modification of the Manouguian technique, with the dotted line extension demonstrating the classical Manouguian technique. The dotted line B represents the incision for the classical Nicks technique. **A** and **B,** Patch repair for the Nunez modification of the Manouguian and Nicks techniques, respectively. Reprinted with permission. © 2017 Lisa Qiu.

the independent variable of interest (ARE) was included in all models and not subject to variable selection. For our risk factor analysis, missing values were stochastically imputed using a multiple imputation method. A systemic search was conducted to exclude highly correlated risk factors. If 2 variables had a high Pearson correlation, the 1 with the largest average absolute correlation was removed from consideration. This procedure removed mean cardiopulmonary bypass time from the analysis because it was highly correlated with cross-clamp time. We conducted 3 prespecified subgroup analyses examining the effect of surgical aortic root enlargement in: (1) patients undergoing AVR alone (ie, without concomitant procedures), (2) patients undergoing AVR with bioprosthetic valves, and (3) patients undergoing ARE with a specific technique (annular enlargement versus noncoronary sinus patch enlargement).

Propensity score matching was performed to account for potential bias arising from treatment selection.[29] We performed 1:1 greedy matching without replacement[30] on a propensity score calculated based on all baseline variables. As a means to ensure that each pair had exactly the same missing pattern, nearest neighbor matching with a widely used caliper width of 0.25 was used to match cases and controls.[31] To assess the performance of the matching, pre- and postmatching covariable imbalance between the comparison cohort as absolute standardized mean differences is reported.[29] Matched-adjusted results for the primary outcome were reported using match-paired methods. Specifically, the effect of ARE was evaluated using McNemar's tests. In addition, to account for the residual imbalance, we used the generalized estimating equation[29,32] to calculate the adjusted effect of surgical ARE.

Statistical significance was indicated throughout by a 2-tailed *P* value <0.05. All analyses were performed using the R project of Statistical Computing version 3.3.1.

RESULTS

Baseline Characteristics and Intraoperative Details

In all, 7039 consecutive patients underwent AVR during the study period, of whom 1854 (26%) underwent ARE with a pericardial patch and 5185 (74%) underwent AVR without ARE. Baseline characteristics of the study cohort are available in Table 1. Mean age was 65±14 years and 37% were female. Important differences were noted in frequency of previous sternotomy, advanced New York Heart Association class, and urgent/emergent status, which were higher in the AVR+ARE group. Mean BSA and frequency of bicuspid aortic valves were lower in the AVR+ARE group.

Operative Details

The operative techniques for ARE have been previously described,[20,33] and operative details are reported in Table 2. Various techniques for ARE were used in this cohort (annular enlargement [Nicks, Nunez, or Manouguian]: 52.0%; noncoronary sinus patch enlargement: 28.7%; or not specified: 19.3%). The patch material used in the majority of patients was bovine pericardium. The majority of both groups underwent concomitant cardiac procedures (ie, coronary bypass, mitral or tricuspid intervention, ascending aorta repair) (AVR+ARE: 68% versus AVR: 67%, *P*=0.31). Average prosthesis size implanted was slightly smaller in the patients who required AVR+ARE (AVR+ARE: 23.4±2.1 versus AVR: 24.1±2.3, *P*<0.001), respectively, as was mean EOAi (AVR+ARE: 0.82±0.15 cm^2/m^2 versus 0.85±0.18 cm^2/m^2, *P*<0.001) (see Figure 3 and Table 3). Rates of bioprosthetic valve implantation were similar between groups (AVR+ARE: 73.4% versus AVR: 73.3%, *P*=0.98). The postoperative EOAi for both AVR and AVR+ARE groups, stratified by the 4 most common aortic valve models implanted, is reported in Table 3. As expected, patients undergoing AVR+ARE required longer cross-clamp (105±39 versus 92±35 minutes, *P*<0.001) and cardiopulmonary bypass times (133±49 versus 117±43 minutes, *P*<0.001).

In-Hospital Outcomes

The prevalence of in-hospital mortality for the entire cohort was 3.4%, and unadjusted mortality was higher after AVR with a root enlargement (AVR+ARE: 4.3% versus AVR: 3.0%, *P*=0.008). When concomitant cardiac procedures were excluded, mortality was not statistically different between the 2 groups (isolated AVR+ARE: 1.7% versus isolated AVR: 1.1%, *P*=0.28). The frequency of early complications was not statistically different between groups, with the exception of low cardiac output and permanent pacemaker implantation, which were higher after AVR+ARE (Table 4). When concomitant procedures and redo operations were excluded, the rate of pacemaker implantation was lower and not statistically different between groups (AVR+ARE: 5.1% versus AVR: 5.5%, *P*=0.75).

Multivariable Analyses

After adjustment for potential confounders, aortic root enlargement was not associated with an increased risk of in-hospital mortality (odds ratio [OR], 1.03; 95% confidence interval [CI], 0.75–1.41; *P*=0.85). The complete logistic regression model for mortality is included in Table 5. Figure 4 summarizes the association between surgical strategy and the outcomes of interest after adjusting for baseline differences between the 2 groups. Aortic root enlargement was not associated with any in-hospital adverse event.

Propensity Score Analysis

After propensity score matching, 88% of the root enlargement group was appropriately matched. Table I in the online-only Data Supplement summarizes the data before and after propensity score matching, resulting in

Table 1. Baseline Characteristics of Patients Undergoing Aortic Valve Replacement With or Without Surgical Root Enlargement

Variable	Aortic Valve Replacement + Surgical Aortic Root Enlargement		Aortic Valve Replacement		*P* Value
	n	(N=1854)	n	(N=5185)	
Age, y		66±14		65±14	0.065
Sex	1854		5184		<0.001
Male		1001 (54.0)		3447 (66.5)	
Female		853 (46.0)		1737 (33.5)	
Comorbidities					
Diabetes mellitus	1853	364 (19.6)	5184	994 (19.2)	0.66
Insulin-dependent	1845	70 (3.8)	5149	161 (3.1)	0.172
Hypertension	1853	1023 (55.2)	5183	2693 (52.0)	0.017
Hyperlipidemia	1852	839 (45.3)	5172	2300 (44.5)	0.55
Current smoker	1848	151 (8.2)	5158	511 (9.9)	0.029
Former smoker	1848	858 (46.4)	5158	2543 (49.3)	0.034
Peripheral vascular disease	1852	199 (10.7)	5184	573 (11.1)	0.73
Chronic obstructive pulmonary disease	1643	81 (4.9)	4513	148 (3.3)	0.004
Dialysis	1854	22 (1.2)	5184	53 (1.0)	0.60
Previous cardiac surgery	1854	339 (18.3)	5170	636 (12.3)	<0.001
Previous myocardial infarction	1854	41 (2.2)	5183	184 (3.5)	0.004
New York Heart Association functional status	1837		5134		<0.001
1		85 (4.6)		421 (8.2)	
2		441 (24.0)		1352 (26.3)	
3		893 (48.6)		2211 (43.1)	
4		418 (22.8)		1150 (22.4)	
Left ventricle ejection fraction	1843		5177		<0.001
>55		1040 (56.4)		2668 (51.5)	
45–55		581 (31.5)		1679 (32.4)	
30–44		190 (10.3)		709 (13.7)	
<30		32 (1.7)		121 (2.3)	
Mean preoperative creatinine, μmol/L	1392	94 +/– 65	3983	97 +/– 63	0.136
Aortic valve disease	1772		5128		<0.001
Stenosis		1197 (67.6)		3201 (62.4)	
Insufficiency		193 (10.9)		960 (18.7)	
Mixed		382 (21.6)		967 (18.9)	
Bicuspid aortic valve	1679	436 (26.0)	5072	1543 (30.4)	<0.001
Urgent/emergent	1854	104 (5.6)	5184	218 (4.2)	0.016
Shock	1854	42 (2.3)	5184	77 (1.5)	0.028
Body surface area	1846	1.86±0.24	5173	1.88±0.23	<0.001
Preoperative hemoglobin	1457	132±17	4293	134±17	0.001

Values are n (%) or mean±SD.

standardized mean differences in covariables that decreased to <10%. ARE was not associated with in-hospital mortality after propensity score matching both with (OR, 1.03; 95% CI, 0.69–1.54; *P*=0.88) and without (OR, 1.08; 95% CI, 0.76–1.54; *P*=0.66) covariable adjustment.

Subgroup Analysis

When the analysis was restricted to patients having isolated AVR with or without surgical ARE, we found that aortic root enlargement was not associated with an increased risk of in-hospital mortality (OR, 1.58; 95%

Table 2. Operative Details

Variable	Aortic Valve Replacement + Surgical Aortic Root Enlargement		Aortic Valve Replacement		*P* Value
	n	(N=1854)	n	(N=5185)	
Root enlargement technique	1854				
Annular enlargement (Nicks, Nunez, or Manouguian)		965 (52.0)			
Noncoronary sinus patch enlargement		532 (28.7)			
Not specified		357 (19.3)			
Patch material used	1854				
Bovine pericardium		1274 (68.7)			
Dacron		168 (9.1)			
CorMatrix		42 (2.3)			
Not specified		370 (20.0)			
Concomitant procedures	1854	1260 (68.0)	5185	3456 (66.7)	0.31
Mitral valve surgery					0.025
Repair		79 (4.3)		268 (5.2)	
Replacement		272 (14.7)		637 (12.3)	
Replacement of ascending aorta	1854	161 (8.7)	5185	534 (10.3)	0.046
Coronary bypass grafting	1854		5185		< 0.001
None		1049 (56.6)		2938 (56.7)	
1 graft		335 (18.1)		728 (14.0)	
2 grafts		224 (12.1)		585 (11.3)	
3–6 grafts		246 (13.3)		934 (18.0)	
Tricuspid valve surgery	1854		5185		0.005
Repair		57 (3.1)		214 (4.1)	
Replacement		12 (0.6)		12 (0.2)	
Congenital	1854	57 (3.1)	5185	157 (3.0)	0.92
Bioprosthetic valve	1801	1322 (73.4)	5185	3803 (73.3)	0.98
Bioprosthetic valve type	1801		5185		<0.001
None		479 (26.6)		1382 (26.7)	
Carpentier-Edwards		621 (34.5)		992 (19.1)	
Hancock II		560 (31.1)		1765 (34.0)	
Other		141 (7.8)		1046 (20.2)	
Mechanical valve type	1801		5185		0.007
None		1322 (73.4)		3803 (73.3)	
St Jude Medical		346 (19.2)		1008 (19.4)	
Carbomedics		56 (3.1)		223 (4.3)	
Other		77 (4.3)		151 (2.9)	
Mean prosthesis size	1796	23±2	5023	24±2	<0.001
Effective orifice area index	1674	0.82±0.15	4705	0.85±0.18	<0.001
Cardiopulmonary bypass, min	1851	133±49	5178	117±43	<0.001
Aortic cross-clamp time, min	1851	105±39	5184	92±35	<0.001
Circulatory arrest	1853	59 (3.2)	5183	240 (4.6)	0.007
Intraaortic balloon pump inserted	1854	77 (4.2)	5185	162 (3.1)	0.043

Values are n (%) or mean±SD.

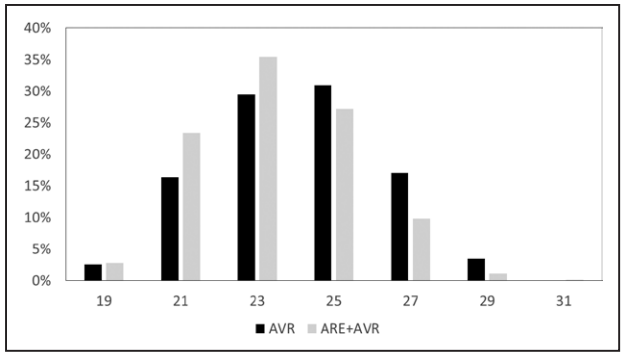

Figure 3. Implanted valve size, by procedure performed.
AVR indicates aortic valve replacement; AVR+ARE, aortic valve replacement + surgical aortic root enlargement; and EOAi, effective orifice area index.

CI, 0.67–3.54; *P*=0.27). Similarly, when the analysis was restricted to patients receiving a bioprosthesis, we found that aortic root enlargement was not associated with an increased risk of in-hospital mortality (OR, 0.87; 95% CI, 0.59–1.27; *P*=0.47).

Differences in patient characteristics and operative results between the 2 main surgical techniques used in this paper (annular enlargement versus noncoronary sinus patch enlargement) are reported in Table II in the online-only Data Supplement. The mean prosthesis size was slightly larger after noncoronary sinus patch enlargement compared with annular enlargement (sinus: 23.6±2.1 versus annular 23.4±2.1, *P*=0.05), although the mean EOAis were not statistically different (sinus: 0.81±0.13 versus annular 0.82±0.15, *P*=0.07). The association of each surgical technique with mortality and the early outcomes of interest are shown in Figure I and II in the online-only Data Supplement. Neither surgical technique was associated with in-hospital mortality. When the 2 main techniques (annular enlargement versus noncoronary sinus repair) were compared directly, we found no difference in early outcomes apart from an increased risk of bleeding after noncoronary sinus repair (OR, 2.56; 95% CI, 1.45–4.59; *P*=0.001).

Table 3. Postoperative Indexed Effective Orifice Area per Aortic Valve Model Implanted

Valve Model	Aortic Valve Replacement + Surgical Aortic Root Enlargement	Aortic Valve Replacement	*P* Value
All valves	0.85±0.18	0.82±0.15	<0.001
All biological	0.78±0.10	0.78±0.10	0.75
Carpentier-Edwards	0.82±0.11	0.80±0.10	0.008
Hancock II	0.75±0.08	0.75±0.08	0.22
All mechanical	0.97±0.22	0.93±0.21	0.001
St Jude	0.96±0.23	0.92±0.21	0.003
Carbomedics	0.98±0.17	0.95±0.14	0.24

Values indicate mean±SD.

DISCUSSION

The most important finding of this paper is that aortic root enlargement may be safely added to AVR without an increased risk of early mortality. Furthermore, the addition of ARE to AVR was not associated with an increased risk of postoperative adverse events. To our knowledge, this is the largest series reporting outcomes after aortic valve replacement with or without aortic root enlargement.

With the increasing use of VIV TAVR for failing bioprosthetic valves, the cardiovascular community has renewed interest in the role of ARE during conventional AVR. Worse outcomes after VIV TAVR have been reported in patients with small (≤21 mm) or intermediate (>21 and <25 mm) sized bioprostheses, those with surgical PPM, and those with postprocedural gradients of ≥20 mm Hg.[4–6] Because the use of biological valves is increasing dramatically, surgeons must consider the possibility of future VIV TAVR when implanting a biological valve in a young patient. ARE should be considered when the internal diameter of a specific valve model and size will be inadequate to achieve a good result with VIV TAVR. Some groups, including ours, have adopted an aggressive approach to the management of a small aortic annulus during AVR to increase the size of the implanted valve in an effort to minimize long-term adverse events and to facilitate future VIV TAVR. Several small single-center studies have presented acceptable results of ARE at the time of AVR,[16,19–23,34,35] demonstrating the technique's feasibility. The incremental risk of adding ARE to AVR, however, has not been previously reported in a large series. Despite the longer cross-clamp and cardiopulmonary bypass times, ARE was not an independent predictor of early mortality or early adverse events.

Various techniques for implanting a larger aortic prosthesis have been described and were used throughout the study period to achieve a similar goal of inserting a larger prosthesis in the aortic valve position. When we examined the perioperative results stratified for the 2 main techniques used in this paper, we found no association with either annular enlargement or the noncoronary sinus patch technique with mortality. Annular enlargement was independently associated with an increased need for permanent pacemaker implantation. Several other strategies are available in the surgeon's armamentarium to address a small aortic root. Stentless aortic valves such as the Toronto SPV valve provide larger EOAi than stented bioprostheses.[36,37] We no longer use these valves, however, given their limited durability and technical complexity at the time of reoperation. Contemporary options to avoid PPM include rapid deployment aortic valve bioprostheses and TAVI, which

Table 4. In-Hospital Outcomes

Variable	Aortic Valve Replacement + Surgical Aortic Root Enlargement		Aortic Valve Replacement		*P* Value
	n	(N=1854)	n	(N=5185)	
Mortality	1854	80 (4.3)	5185	156 (3.0)	0.008
Reoperation for bleeding	1854	110 (5.9)	5185	270 (5.2)	0.23
Acute myocardial infarction	1853	21 (1.1)	5182	62 (1.2)	0.90
Low cardiac output	1849	114 (6.2)	5179	242 (4.7)	0.013
Permanent pacemaker	1853	169 (9.1)	5179	358 (6.9)	0.002
Infection	1853		5179		
Superficial sternal wound		13 (0.7)		44 (0.8)	0.65
Deep sternal wound		12 (0.6)		34 (0.7)	1.00
Sepsis		41 (2.2)		101 (2.0)	0.50
Atrial fibrillation	1853	497 (26.8)	5179	1287 (24.8)	0.093
Transient ischemic attack	1853	13 (0.7)	5183	22 (0.4)	0.176
Stroke	1853	46 (2.5)	5184	125 (2.4)	0.86
Renal failure (dialysis)	1853	39 (2.1)	5183	95 (1.8)	0.64

Values indicate n (%).

have also been shown to provide higher EOAi.[38,39] We currently reserve both options for patients with significant comorbidities and lower life expectancy because their long-term durability is unknown.

Despite our aggressive management of a small aortic root at the time of AVR, mean EOAi in the AVR+ARE group was 0.82±0.15 cm^2/m^2 and was smaller than the AVR group. We presume that the EOAi for patients undergoing AVR+ARE would have been even smaller without a root enlargement. The exact degree of enlargement obtained by these ARE techniques cannot be ascertained from these data and would require a prospective study. We use surgical ARE liberally, particularly in young and active patients with a high BSA who are at risk of mismatch or may return for VIV TAVR. We believe Hancock II to be more durable than currently available pericardial valves,[40,41] but its hemodynamic performance is inferior.[42,43] In patients where durability is an issue (patients 50–70 years of age), we favored this bioprosthesis with liberal use of root enlargement to avoid PPM. This partly accounts for the high proportion of the ARE group 686/1854 (37.0%) that had an implanted valve with a labeled size ≥25. In patients in whom PPM is likely (ie, small aortic root and high BSA), particularly those who are older (>70 years of age), we tend to favor pericardial valves that provide a larger postoperative EOAi.

LIMITATIONS

This is an analysis of a large cohort of patients undergoing aortic valve replacement with or without root enlargement with careful determination of all early morbidity and mortality. The main limitations of this study stem from its retrospective nature. Although multiple strategies were used to account for differences between the groups, we could not account for other potential unmeasured confounders. The decision regarding whether to enlarge the root, and the specific technique and patch material that was used, was at the discretion of the surgeon. Furthermore, this study reports the results from a single center where ARE is done

Table 5. Multivariable Analysis Using Logistic Regression for In-Hospital Mortality

Covariable	Multivariable Odds Ratio (95% CI)	*P* Value
Aortic root enlargement	1.031 (0.750–1.405)	0.85
Age, per 10 y	1.219 (1.073–1.392)	0.003
Hyperlipidemia	0.714 (0.523–0.971)	0.033
Peripheral vascular disease	2.015 (1.406–2.858)	<0.001
Mean preoperative creatinine	1.003 (1.001–1.004)	<0.001
Aortic valve disease		
Insufficiency	1.370 (0.897–2.059)	0.137
Mixed	1.555 (1.090–2.197)	0.013
Urgent/emergent	2.333 (1.453–3.638)	<0.001
Mean preoperative hemoglobin	0.972 (0.964–0.980)	<0.001
Replacement of ascending aorta	1.622 (1.027–2.484)	0.031
Tricuspid valve replacement/repair	2.420 (1.499–3.802)	<0.001
Mean aortic cross clamp time, per 20 min*	1.347 (1.258–1.442)	<0.001
Intraaortic balloon pump inserted	11.520 (8.034–16.437)	<0.001

CI indicates confidence interval.
*Odds ratio was calculated based on an increase of 20 minutes of cross-clamp time.

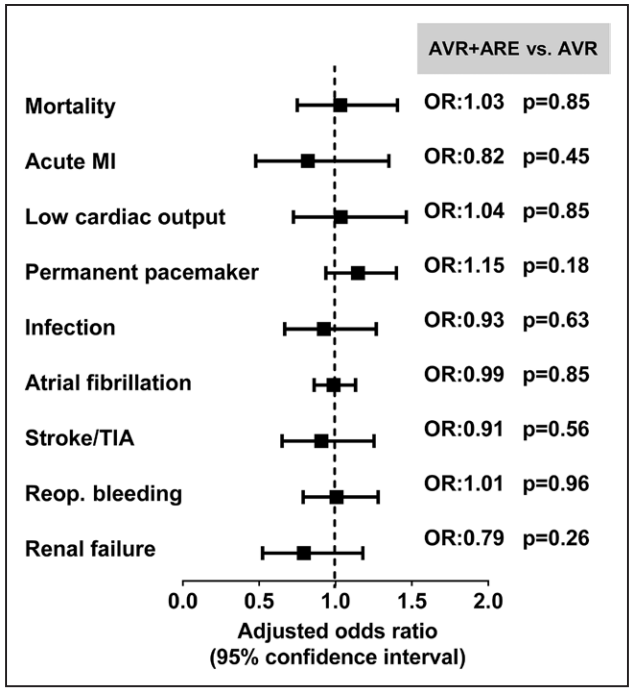

Figure 4. Association of surgical aortic root enlargement with early outcomes of interest: multivariable analyses. AVR indicates aortic valve replacement; AVR+ARE, aortic valve replacement + aortic root enlargement; MI, myocardial infarction; OR, odds ratio; and TIA, transient ischemic attack.

quite liberally, thus potentially limiting the generalizability of these results to other centers. The reassuring results with surgical ARE reported here and in previous small-center experiences may be subject to publication bias, and it is unclear whether surgeons with less experience would have similar results. Nonetheless, to our knowledge, this reports the largest institutional experience with aortic root enlargement. As such, these data may provide guidance regarding the perioperative risks of performing a root enlargement at the time of AVR.

CONCLUSIONS

In the largest analysis to date, surgical enlargement of the aortic root was not associated with increased risk of mortality or adverse events. We suggest that surgeons carefully consider their patients' age and BSA, the internal orifice of their chosen valve model and size, and the suitability for future VIV TAVR at the time of surgical AVR. Aggressive management of a small aortic annulus with a root enlargement should be considered, along with adequate evaluation of associated risk factors and proper valve selection. Surgical ARE is a safe adjunct to AVR in the modern era.

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