Importance of surgeon's experience in practicing valve-sparing aortic root replacement

Kavya Rajesh, BS,[a] Megan Chung, BA,[a] Dov Levine, MD,[a] Elizabeth Norton, MD,[b] Parth Patel, MD,[b] Yu Hohri, MD, PhD,[a] Chris He, BS,[b] Paridhi Agarwal, BS,[b] Yanling Zhao, MS, MPH,[c] Pengchen Wang, MS,[c] Paul Kurlansky, MD,[c] Edward Chen, MD,[d] and Hiroo Takayama, MD, PhD[a]

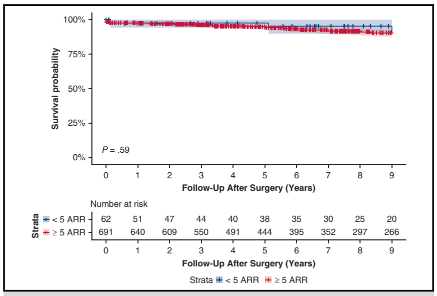
ABSTRACT

Background: Valve-sparing root replacement (VSRR) requires a unique skill set. This study aimed to examine the influence of surgeon's procedural volume on outcomes of VSRR.

Methods: This retrospective study included 1697 patients from 2 large, high-volume aortic centers who underwent aortic root replacement (ARR) between 2004 and 2021 and were potentially eligible for VSRR. Surgeons were classified as performing <5 ARRs or ≥5 ARRs annually. Multivariable logistic regression was used to examine the independent association of surgeon volume and the decision to perform VSRR. Inverse probability treatment weighting (IPTW) was used to match patients who were operated on by <5 ARR surgeons or ≥5 ARR surgeons and compare long-term survival probability. Cumulative incidence curves with mortality as a competing risk were plotted to compare the rate of aortic valve reoperation.

Results: Of 1697 patients who met the study inclusion criteria, 944 underwent composite-valve conduit ARR and 753 underwent VSRR. The median age of the cohort was 57 years (interquartile range, 45-66 years), and 268 (15.8%) were female. Aortic insufficiency was present in 1105 patients (65.1%), and 200 of the procedures (11.8%) were reoperations. The indication for surgery was aneurysm in 1496 patients (88.2%) and dissection in 201 (11.8%). Among the 743 patients who underwent VSRR, 691 (92%) were operated on by ≥ 5 ARR surgeons and 62 (8%) were operated on by <5 ARR surgeons. In multivariable logistic regression, ≥5 ARRs (odds ratio, 3.33; 95% confidence interval, 2.34-4.73; $P < .001$) was associated with VSRR as the procedure of choice. Following IPTW, there was no significant difference between <5 ARR and ≥5 ARR surgeons in survival probability after VSRR ($P = .59$) or in the rate of aortic valve reoperation ($P = .60$).

Conclusions: In the setting of a high-volume aortic center, patients who undergo ARR are less likely to receive VSRR if operated on by a <5 ARR surgeon; however, VSRR may be safely performed by <5 ARR surgeons. (JTCVS Open 2024;21:19-34)



KM curve of IPTW balanced cohort.

CENTRAL MESSAGE

Patients who undergo valve-sparing root replacement at high-volume aortic centers have similar outcomes regardless of annual surgeon volume.

PERSPECTIVE

Valve-sparing root replacement is a technically challenging and complex procedure. Little is known about the outcomes of such procedures performed by surgeons with different annual case volumes at the same aortic center. In this study, we describe short- and long-term outcomes of patients who undergo valve-sparing root replacement based on annual case volume of operating surgeon.

Contemporary guidelines are increasingly including recommendations for case volume thresholds for technically demanding cardiac procedures, such as mitral valve (MV) repair and septal myectomy.[1,2] In patients with hypertrophic cardiomyopathy undergoing septal myectomy and alcohol septal ablation, low annual case volumes (by center and surgeon) are associated with greater early mortality and postoperative complications.[3-5] For MV repair, the learning

From the [a]Division of Cardiothoracic and Vascular Surgery, New York Presbyterian Hospital, Columbia University Medical Center, New York, NY; [b]Division of Cardiothoracic Surgery, Department of Surgery, Emory University School of Medicine, Atlanta, Ga; [c]Center for Innovation and Outcomes Research, Columbia University, New York, NY; and [d]Division of Cardiovascular and Thoracic Surgery, Duke University Medical Center, Durham, NC.

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Address for reprints: Hiroo Takayama, MD, PhD, Division of Cardiothoracic and Vascular Surgery, New York Presbyterian Hospital, Columbia University Medical Center, 177 Fort Washington Ave, New York, NY 10032 (E-mail: ht2225@cumc.columbia.edu).

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Abbreviations and Acronyms

AI = aortic insufficiency
ARR = aortic root replacement
AV = aortic valve
CI = confidence interval
CVC = composite valved conduit
IPTW = inverse probability treatment weighting
LVEF = left ventricular ejection fraction
MV = mitral valve
OR = odds ratio
VSRR = valve-sparing root replacement

curve to develop proficiency has been examined, leading to a suggestion of a recommended case volume per surgeon and center.[6,7] Increased annual hospital and surgeon procedure volume have been associated with increased probability of MV repair over MV replacement for mitral regurgitation as well as decreased 30-day and 1-year mortality.[8,9]

VSRR has become an established surgical option for patients with preserved cusp integrity.[10] Preservation of native valve has advantages over a composite valved conduit (CVC) with a prosthetic aortic valve, including the ability to avoid the anticoagulation associated with mechanical valves and the structural valve degeneration associated with bioprosthetic valves.[11] Aortic valve-sparing operations require surgical expertise, which may be related to the variability in the reported rates of aortic reintervention after VSRR.[12,13] To this point, it is important to note that the Society of Thoracic Surgeons database shows that only 5% of sites perform >16 aortic root operations annually, and the median annual number of ARRs per site is 2.[14] Patients undergoing ARR at North American hospitals that perform fewer than 30 to 40 such procedures annually have greater risk-adjusted mortality than those undergoing surgery in higher-volume hospitals.[15] In a study of ARR in Medicare patients, surgeons who performed at least 5 cases/year had a greater reduction in the odds of perioperative death compared to those who performed fewer than 5 cases/year.[16] Conversely, some studies have suggested that thoracic aortic surgery may be performed with similar results by high-volume surgeons and low-volume surgeons at the same institution.[17]

Although the need for surgical expertise to optimize VSRR outcomes is widely acknowledged in the surgical community, related literature is scarce. Examining the influence of surgical proficiency on outcomes would help establish a process to ensure the quality of this complex procedure with the goal of providing more patients with the benefits of VSRR.

To address this knowledge gap, we studied the probability of undergoing VSRR and success of the operation stratified by surgeon's ARR volume in the setting of 2 high-volume aortic centers.

METHODS

Ethical Statement

This study was approved by the Institutional Review Boards of Columbia University Irving Medical Center and Emory University with a waiver of consent (Columbia: Aaau0575, April 4, 2022; Emory: Irb00001479, August 30, 2021).

Study Design

This 2-center retrospective study included 1697 patients undergoing ARR who were potentially eligible for VSRR (as described above) between March 23, 2004, and February 18, 2021, at Columbia University and Emory University. The mean center volume for VSRR was 23 cases/year at Columbia and 21 cases/year at Emory. The endpoints of interest were in-hospital postoperative complications, postoperative transesophageal echocardiography and transthoracic echocardiography, operative mortality, aortic valve reoperation, and long-term mortality. Data were collected for all patients from our Aortic Center Database and the electronic medical record from the 2 institutions. Definitions of the postoperative complications followed those of the Society of Thoracic Surgeons Adult Cardiac Surgery Database.[18] All-cause mortality during the follow-up period was collected through clinical encounters as well as phone calls to patients and referring physicians. For the patients at Columbia, death information was supplemented with the Centers for Disease Control and Prevention National Death Index, accessed on May 26, 2021, and complete to December 31, 2019.[19] The median duration of follow-up was 6.30 years (interquartile range [IQR], 5.92-6.65 years), constituting 9781 patient-years.

To examine the relevance of surgeon's experience with aortic root and valve operations on the outcomes of VSRR, we focused on surgeon's procedural volume, calculated by dividing the total number of ARRs performed by the surgeon by the total days between the first and last operation recorded in the database. This calculation included bioprosthetic and mechanical root replacement and was not limited to VSRR procedures. ARR was chosen to represent the surgeon's experience and proficiency required to perform VSRR, given the procedural similarities in ARR and VSRR. A cutoff of 5 ARRs/year was chosen based on a histogram of surgeon volume distribution and clinical acumen.[16]

Study Population

To select candidates for VSRR among the 2701 patients who underwent aortic root replacement, 1004 patients who were ineligible for VSRR were excluded, including 529 patients with moderate/severe aortic stenosis, 425 with a prior aortic valve procedure, 29 with a Ross or homograft root replacement, 20 with a surgical indication for endocarditis, and 1 transcatheter aortic valve explant with ARR (Figure 1). This left 944 patients with CVC and 753 patients with VSRR for inclusion in this study.

Patient Management

The operating surgeon determined the type of surgical procedure, taking multiple factors into consideration, such as acute illness, comorbidities, extent of necessary concomitant procedures, valve integrity (stenosis, calcifications, fibrosis, cusp configuration, or fenestrations), and patient preference. Surgical management for aortic root replacement at both institutions has been described previously.[20-23] Surgical indication was determined by the attending surgeon, based on the most recent American Heart Association/American College of Cardiology guidelines.[24] When concomitant hemiarch/transverse aortic procedures were necessary, the arterial cannulation site and method of cerebral protection were at the surgeon's discretion.[25,26] Management of cardiopulmonary bypass was

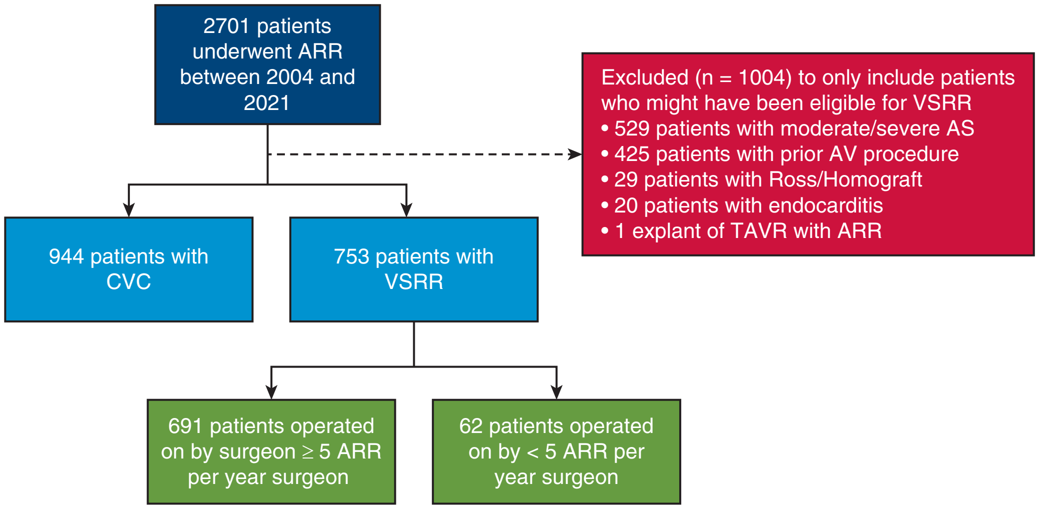

FIGURE 1. Diagram depicting selection of patients who underwent aortic root replacement. *ARR*, Aortic root replacement; *VSRR*, valve-sparing root replacement; *AS*, aortic stenosis; *AV*, aortic valve; *TAVR*, transcatheter aortic valve replacement; *CVC*, composite valved conduit.

standard throughout the study period. Standard bypass parameters were mild hypothermia (32 °C) with a pump flow rate of 2.5 mL/cm^2/minute and a goal mean arterial pressure of 60 to 80 mm Hg. The aortic valve was spared during root replacement with a reimplantation technique when appropriate; when replacement was necessary, the prosthetic valve was chosen based on American Heart Association/American College of Cardiology guidelines and patient preference.

Statistical Analysis

Categorical variables are reported as count and percentage. The normality of continuous variables was assessed using the Shapiro-Wilk test and reported as median and IQR, and comparisons were made using the Mann-Whitney *U* test when the normality assumption was violated. Categorical variables were compared using the χ^2 or Fisher exact test as appropriate. No patient demographics or operative characteristics were missing, and thus data imputation was not performed.

To determine the cutoff for surgeon volume as a categorical variable, an adjusted cubic spline was used to determine the possible nonlinear relationship between annual ARR volume and the probability of undergoing VSRR. Using a combination of cubic spline results and histogram of surgeon volume distribution, performing at least 5 ARRs/year was chosen to create groups for comparison (Figures E1 and E2).

Univariable and multivariable logistic regression analyses were performed to determine which variables were associated with undergoing VSRR (Table E3). Variables for inclusion in the final multivariable analyses were chosen based on results from univariable analysis and clinical acumen. All variables were checked for multicollinearity, and variance inflation factors <5 were obtained in regression models, indicating minimum potential collinearity among variables. In this analysis, an odds ratio (OR) > 1 indicated an increased likelihood of undergoing VSRR and an OR <1 indicated a decreased likelihood.

Inverse probability of treatment weighing (IPTW) based on trimmed stabilized weights was used to adjust potential confounding effects in baseline characteristics between the VSRR group and the CVC group. These characteristics included age, sex, body mass index, diabetes mellitus, chronic kidney disease, hypertension, cerebrovascular disease, reoperation, dissection, dyslipidemia, connective tissue disease, moderate/severe aortic insufficiency (AI), and left ventricular ejection fraction (LVEF). Matching success was determined by a standardized mean difference <0.1 on variables after matching. Survival curves were derived using the Kaplan-Meier method and compared using the log-rank test. The Fine and Gray model was used to estimate and compare the cumulative incidence of aortic valve reoperation while accounting for mortality as a competing event. We performed a similar analysis in patients who underwent ARR with CVC operated on by <5 ARR surgeons or ≥5 ARR surgeons (Appendix E1). Furthermore, a subgroup analysis was performed for selected surgeons with an annual ARR volume of least 15 (≥15 ARR surgeons). Satisfactory matching with a standardized mean difference <0.1 was achieved after matching in all analyses. For all analyses, a *P* value < .05 was considered statistically significant. Statistical analyses were performed with R version 4.2.1 (R Foundation for Statistical Computing).

RESULTS

Patient Characteristics

A total of 1697 patients who underwent ARR were included (annual surgeon volume <5 ARRs, n = 252; ≥5 ARRs, n = 1445), as described in Figure 1. The baseline characteristics of all patients are listed in Table 1, stratified by annual surgeon volume. The median patient age was 57 years (IQR, 45-66 years), and 268 (15.8%) were females. The indication for surgery was dissection in 201 patients (11.8%) and moderate/severe AI in 1105 (65.1%). The median LVEF was 55% (IQR, 50%-60%).

Operative Details

Operative details are presented in Table 2. Of the 1697 patients who underwent ARR, 803 (47.3%) had a biological CVC, 141 (8.3%) had a mechanical CVC, and 753 (44.4%) had a VSRR. Regarding concomitant procedures, 706 patients (41.6%) had a hemiarch replacement and 160 (9.4%) had a partial or total arch replacement. The median cardiopulmonary bypass time was 189 minutes (IQR, 144-233 minutes), and the median aortic cross-clamp time was 159 minutes (IQR, 118-197 minutes).

TABLE 1. Patient demographics of patients who underwent ARR, overall and stratified by annual surgeon volume

Characteristic	Overall	<5 ARRs	≥5 ARRs	*P* value
Number	1697	252	1445	
Age, y, median (IQR)	57 (45-66)	57 (43-65)	57 (46-66)	.39
Female sex, n (%)	268 (15.8)	41 (16.3)	227 (15.7)	.90
BMI, median (IQR)	27.8 (24.6-31.6)	28.4 (25.0-32.4)	27.8 (24.6-31.4)	.13
CKD, n (%)	308 (18.1)	49 (19.4)	259 (17.9)	.63
DM, n (%)	186 (11.0)	27 (10.7)	159 (11.0)	.98
HTN, n (%)	1286 (75.8)	200 (79.4)	1086 (75.2)	.17
Surgical indication, n (%)				<.001
Aneurysm	1496 (88.2)	193 (76.6)	1303 (90.2)	
Dissection	201 (11.8)	59 (23.4)	142 (9.8)	
Dyslipidemia, n (%)	885 (52.2)	125 (49.6)	760 (52.6)	.42
CVD, n (%)	123 (7.2)	23 (9.1)	100 (6.9)	.27
PVD, (%)	130 (7.7)	12 (4.8)	118 (8.2)	.08
Connective tissue disease, n (%)	100 (5.9)	13 (5.2)	87 (6.0)	.70
Bicuspid AV, n (%)	420 (24.7)	56 (22.2)	364 (25.2)	.35
Moderate/severe AI, n (%)	1105 (65.1)	186 (73.8)	919 (63.6)	.002
Previous MI, n (%)	43 (5.7)	5 (6.4)	38 (5.7)	.99
Reoperation, n (%)	200 (11.8)	32 (12.7)	168 (11.6)	.70
LVEF, %, median (IQR)	55 (50-60)	55 (50-60)	55 (51-60)	.59

ARR, Aortic root replacement; *IQR*, interquartile range; *BMI*, body mass index; *CKD*, chronic kidney disease; *DM*, diabetes mellitus; *HTN*, hypertension; *CVD*, cerebrovascular disease; *PVD*, peripheral vascular disease; *AV*, aortic valve; *AI*, aortic insufficiency; *MI*, myocardial infarction; *LVEF*, left ventricular ejection fraction.

Probability of Undergoing VSRR

Multivariable logistic regression for undergoing VSRR versus non-VSRR (biological or mechanical CVC) is shown in Table 3. Older age (OR, 0.95; 95% CI, 0.94-0.96; $P < .001$), chronic kidney disease (OR, 0.53; 95% CI, 0.38-0.74; $P < .001$), cerebrovascular disease (OR, 0.60; 95% CI, 0.37-0.97; $P = .04$), bicuspid AV (OR, 0.40; 95% CI, 0.31-0.53; $P < .001$), moderate/severe AI (OR, 0.25; 95% CI, 0.20-0.32; $P < .001$), reoperation (OR, 0.30; 95% CI, 0.20-0.45; $P < .001$), concomitant aortic

TABLE 2. Operative characteristics of patients who underwent ARR, overall and stratified by annual surgeon volume

Characteristic	Overall	<5 ARRs	≥5 ARRs	*P* value
Number	1697	252	1445	
Type of root replacement, n (%)				<.001
Biologic CVC	803 (47.3)	130 (51.6)	673 (46.6)	
Mechanical CVC	141 (8.3)	60 (23.8)	81 (5.6)	
VSRR	753 (44.4)	62 (24.6)	691 (47.8)	
Concomitant aortic procedure, n (%)				.001
Hemiarch	706 (41.6)	94 (37.3)	612 (42.4)	
Partial/total arch	160 (9.4)	11 (4.4)	149 (10.3)	
Concomitant MV procedure, n (%)	88 (5.2)	9 (3.6)	79 (5.5)	.27
Concomitant CABG, n (%)	294 (17.3)	57 (22.6)	237 (16.4)	.02
CPB time, min, median (IQR)	189 (144-233)	206 (175-257)	185 (139-230)	<.001
Cross-clamp time, min, median (IQR)	159 (118-197)	164 (135-195)	157 (114-198)	.01
Circulatory arrest, n (%)	878 (51.7)	121 (48.0)	757 (52.4)	.13

ARR, Aortic root replacement; *CVC*, composite-valved conduit; *VSRR*, valve-sparing root replacement; *MV*, mitral valve; *CABG*, coronary artery bypass graft; *CPB*, cardiopulmonary bypass; *IQR*, interquartile range.

TABLE 3. Multivariable logistic regression for undergoing VSRR versus non-VSRR

Variable	OR (95% CI)	*P* value
Age	0.95 (0.94-0.96)	<.001
CKD	0.53 (0.38-0.74)	<.001
DM	0.94 (0.63-1.38)	.74
HTN	0.93 (0.70-1.25)	.63
Dissection	0.73 (0.50-1.08)	.11
Dyslipidemia	0.95 (0.74-1.22)	.68
CVD	0.60 (0.37-0.97)	.04
Bicuspid AV	0.40 (0.31-0.53)	<.001
Moderate/severe AI	0.25 (0.20-0.32)	<.001
Reoperation	0.34 (0.23-0.51)	<.001
LVEF	1.03 (1.02-1.04)	<.001
Concomitant arch replacement	0.68 (0.53-0.86)	.002
Concomitant MV procedure	0.46 (0.26-0.81)	.007
Concomitant CABG	0.83 (0.60-1.13)	.23
≥5 ARR	3.33 (2.34-4.73)	<.001

VSRR, Valve-sparing root replacement; *OR*, odds ratio; *CI*, confidence interval; *CKD*, chronic kidney disease; *DM*, diabetes mellitus; *HTN*, hypertension; *CVD*, cerebrovascular disease; *AV*, aortic valve; *AI*, aortic insufficiency; *LVEF*, left ventricular ejection fraction; *MV*, mitral valve; *CABG*, coronary artery bypass graft; *ARR*, aortic root replacement.

arch replacement (OR, 0.68; 95% CI, 0.53-0.86; $P = .002$), and concomitant MV procedure (OR, 0.46; 95% CI, 0.26-0.81; $P = .007$) and were negatively associated with undergoing VSRR, while LVEF (OR, 1.03; 95% CI, 1.02-1.04; $P < .001$) and annual surgeon volume ≥5 ARRs (OR, 3.33 ; 95% CI, 2.34-4.73; $P < .001$) were positively associated with VSRR.

Outcomes of VSRR Performed by <5 ARR Surgeons Versus ≥5 ARR Surgeons

Baseline characteristics for patients undergoing VSRR after IPTW comparing <5 ARR and ≥5 ARR are shown in Table 4. Prematch patient demographics and operative characteristics for subgroup of patients undergoing VSRR are shown in Tables E1 and E2. After IPTW, there was no significant difference in in-hospital mortality, postoperative complications, and postoperative transesophageal echocardiography or predischarge transthoracic echocardiography AI seen in VSRR performed by <5 ARR surgeons versus ≥5 ARR surgeons (Table 5). Interestingly, for patients undergoing ARR with CVC, in-hospital mortality was higher with <5 ARR surgeons after IPTW (Tables E4 and E5).

Long-Term Outcomes of the VSRR Cohort

A Kaplan-Meier curve of the IPTW-balanced cohort among patients who underwent VSRR operated on by <5 ARR surgeons versus ≥5 ARR surgeons showed no significant difference in survival probability over 9 years ($P = .59$), as shown in Figure 2. The cumulative incidence curve of AV reoperation with mortality as a competing risk among patients who underwent VSRR operated on by <5 ARR surgeons versus ≥5 ARR surgeons also showed no significant difference over the follow-up period ($P = .6$), as shown in Figure 3.

Analysis of Extremely High-Volume Surgeons

There were 4 surgeons who performed ≥15 ARRs annually who accounted for 689 patients in the database at the "extreme" end of the annual surgeon volume distribution. Baseline characteristics of patients operated on by <5 ARR surgeons and ≥15 ARR surgeon after IPTW are compared in Table E6. After matching, there are no significant differences in short or long-term mortality, postoperative complications, or AI (Table E7 and Figure E3).

DISCUSSION

Our study is the first to compare VSRR performed by cardiac surgeons with different annual case volumes of ARR. We demonstrated that (1) patients operated on by ≥ 5 ARR surgeons were more likely to undergo VSRR than CVC, (2) regardless of surgeon ARR volume, patients who underwent VSRR had similar rates of postoperative mortality and complications, degree of residual AI on predischarge echocardiography, rates of long-term mortality, and rates of AV reoperation.

Our study uniquely demonstrates the increased probability of undergoing VSRR when operated on by a high-volume surgeon. One possible reason could be related to underlying patient demographics. In our centers, <5 ARR surgeons operated on more patients with dissection and moderate/severe AI. However, operation performed by a <5 ARR surgeon was still significant when controlling for these factors, suggesting that surgeon volume continues to have a strong effect on ARR type. A constellation of comorbidities associated with less "healthy" patients are linked to a lower likelihood of undergoing VSRR, while patients with a higher LVEF who could be "healthier" undergo more VSRRs. Although VSRR is performed less commonly in acute type A aortic dissection, VSRR is associated with reduced mortality compared to CVC in these patients.[27] Our excellent long-term survival can suggest increased use of VSRR in patients with dissection. There also were more mechanical CVCs implanted by <5 ARR surgeons in our study. Because these CVCs typically are preferred in younger patients due to increased durability, less experienced surgeons may be opting for a mechanical CVC compared to VSRR.[28]

MV repair is a similar, technically complex procedure in which outcomes have been shown to improve with increased surgeon and center volume.[6,7] Higher total annual

TABLE 4. Patient demographics among those who underwent VSRR after IPTW match between <5 ARR and ≥5 ARR surgeons

Characteristics	<5 ARRs	≥5 ARRs	*P* value	SMD
Number	59.3	690.9		
Age, y, median (IQR)	52 (38-60)	50 (39-61)	.99	0.024
Female sex, n (%)	9.8 (16.6)	115.6 (16.7)	.97	0.005
BMI, median (IQR)	27.6 (25.3-30.7)	27.7 (24.5-31.6)	.71	0.001
DM, n (%)	4.8 (8.1)	56.0 (8.1)	.99	0.001
CKD, n (%)	6.4 (10.8)	72.5 (10.5)	.94	0.010
HTN, n (%)	39.7 (67.0)	473.5 (68.5)	.80	0.033
CVD, n (%)	2.9 (4.9)	31.1 (4.5)	.87	0.019
Reoperation, n (%)	4.1 (7.0)	53.2 (7.7)	.84	0.028
Dissection, n (%)	7.2 (12.1)	63.5 (9.2)	.47	0.096
Dyslipidemia, n (%)	26.0 (43.9)	312.8 (45.3)	.84	0.027
Connective tissue disease, n (%)	6.5 (10.9)	72.4 (10.5)	.91	0.015
Moderate/severe AI, n (%)	29.9 (50.4)	325.7 (47.1)	.63	0.065
LVEF, %, median (IQR)	55 (55-60)	55 (54-60)	.81	0.005

VSRR, Valve-sparing root replacement; *IPTW*, inverse probability treatment weighting; *ARR*, aortic root replacement; *SMD*, standardized mean difference; *IQR*, interquartile range; *BMI*, body mass index; *DM*, diabetes mellitus; *CKD*, chronic kidney disease; *HTN*, hypertension; *CVD*, cerebrovascular disease; *AI*, aortic insufficiency; *LVEF*, left ventricular ejection fraction.

surgeon volume is associated with increased repair rates of degenerative MV disease compared to MV replacement.[7] Interestingly, surgeons with lower annual MV surgery volumes had higher repair rates when operating in the same institution as high-volume surgeons.[7] We found the same result for VSRR in our study. When VSRR was pursued, the results were satisfactory and comparable to those for ≥5 ARR surgeons. Although these results may encourage surgeons who perform fewer ARRs annually to consider attempting more VSRRs, they need to be interpreted in the context of the fact that all patients were managed at high-volume centers, and although their primary surgeons might not perform as many ARRs each year, they may be influenced by and consult with more experienced surgeons as needed. Our data suggest that working in the context of a high-volume center can help ameliorate the volume–

TABLE 5. Results of IPTW among patients who underwent VSRR comparing <5 ARR surgeons and ≥5 ARR surgeons

Variable	<5 ARRs	≥5 ARRs	*P* value
Number	59.3	690.9	
In-hospital mortality (%)	0.7 (1.2)	9.1 (1.3)	.95
Stroke (%)	0.7 (1.2)	13.1 (1.9)	.67
Renal failure (%)	1.8 (3.1)	26.0 (3.8)	.79
Postoperative dialysis (%)	0.7 (1.2)	16.1 (2.3)	.52
Respiratory failure (%)	8.4 (14.2)	74.6 (10.8)	.44
Reoperation for bleeding (%)	5.2 (8.7)	29.2 (4.2)	.12
Postoperative TEE AI (%)			.27
None/trace	23.7 (72.6)	499.8 (84.6)	
Mild	8.2 (25.2)	79.8 (13.5)	
Moderate	0.7 (2.2)	10.0 (1.7)	
Severe	0.0 (0.0)	1.0 (0.2)	
Predischarge TTE AI (%)			.98
None/trace	47.2 (87.1)	580.3 (87.4)	
Mild	6.2 (11.4)	75.6 (11.4)	
Moderate	0.8 (1.5)	8.0 (1.2)	

IPTW, Inverse probability treatment weighting; *VSRR*, valve-sparing root replacement; *ARR*, aortic root replacement; *TEE*, transesophageal echocardiography; *AI*, aortic insufficiency; *TTE*, transthoracic echocardiography.

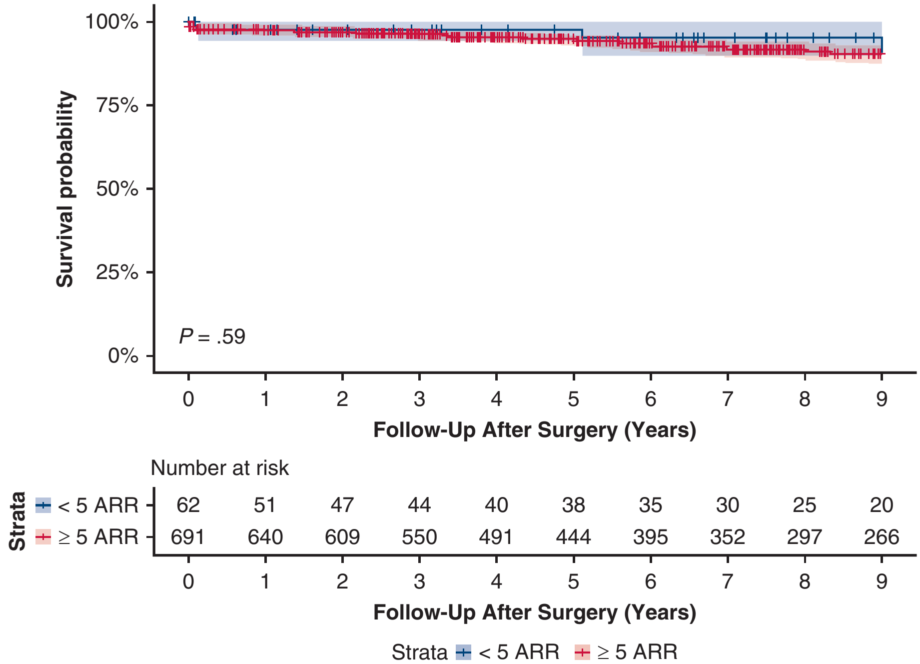

FIGURE 2. Kaplan-Meier curve (with 95% confidence interval) of inverse probability treatment weighting–balanced cohort among patients (rounded to the nearest whole number) who underwent valve-sparing root replacement. *ARR*, Aortic root replacement.

outcome relationship for low-volume surgeons seen in cardiac surgery.[3,6,8,15,29,30] A similar volume–outcome relationship has been noted in general surgery, and there has been an overall increase in cases performed by high-volume surgeons across specialties.[31-33] Whether our results are related to the knowledge transfer from the high-volume surgeons and/or the impact of the collective team effort in appropriately selecting and caring for these patients cannot be determined but is certainly a fruitful topic for further research. Furthermore, large database studies looking at changes in the performance and outcomes of VSRR over time as individual surgeons gain more experience could help guide future practice. It would be interesting to observe whether individual surgeons' approaches and outcomes change as their volume of ARR increases and surgical experience grows over time.

Additionally, an annual ARR volume of ≤5 might not be considered "low" per se. While we chose a cutoff of 5 based on distribution of case volumes from our centers, there is wide variation in the number of operations performed by cardiac surgeons across the country. Our analysis of extremes in our database comparing extremely high-volume surgeons performing ≥15 ARRs showed similar results. A Society of Thoracic Surgeons database study from 2014 found that most cardiac centers performed aortic root surgery in small volumes, with most centers performing 2 or fewer ARRs annually.[14] Together with the similar findings for MV repair, our study emphasizes the importance of program experience in addition to surgeon experience.

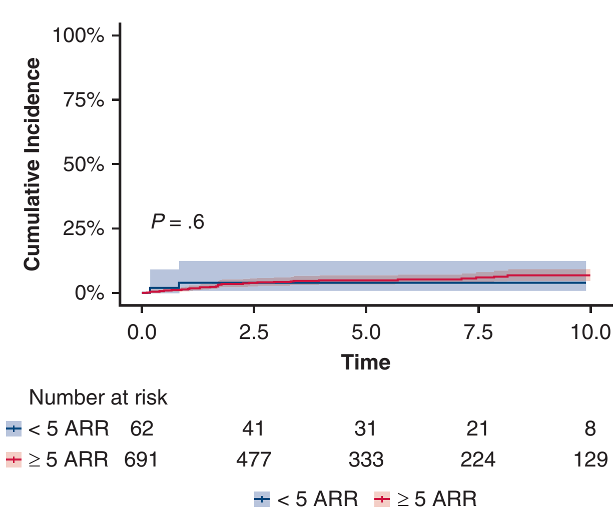

FIGURE 3. Cumulative incidence curve (with 95% confidence interval) of aortic valve reoperation among patients who underwent valve-sparing root replacement with mortality as a competing risk. *ARR*, Aortic root replacement.

Limitations

The limitations of this study are related to its retrospective nature. ARR might not be a perfect surrogate for examining surgical proficiency, necessary to perform VSRR, which often requires aortic valve repair; however, we believe it is the best one available. Although this is a 2-center study with high-volume aortic centers, the associations that we reported between annual surgeon volume and probability of VSRR cannot be viewed as causation and might not be generalizable. Examining the outcomes of VSRR cases based on total career case volume also would be interesting; however, we do not have access to information on cases performed by our surgeons outside our institutions and beyond the dates of surgery to which we have access. Although the number of patients is considerable for a VSRR study, we are still limited by the available sample size and may be underpowered to detect certain differences. Furthermore, we are limited by the small sample size of VSRRs performed by <5 ARR surgeons. While we were still able to balance the cohorts using IPTW, a larger sample size could pick up more detailed differences, particularly in bypass and cross-clamp times and surgical minutiae. We also lacked complete long-term echocardiographic data to study the durability of VSRR in these 2 groups over time. Finally, all operations were performed at 2 specialized, high-volume aortic centers, and thus our results might not be generalizable to other settings.

CONCLUSIONS

Patients who undergo ARR with a ≥5 ARR surgeon are more likely to receive a VSRR than a CVC. VSRRs performed by <5 ARR surgeons and ≥5 ARR surgeons are associated with comparable short- and long-term clinical outcomes.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: valve-sparing root replacement, surgeon volume, aortic root replacement, inverse probability treatment weighting

APPENDIX E1

Baseline characteristics for patients undergoing ARR with CVC after IPTW are compared in the <5 ARR and ≥5 ARR groups in Table E4. After IPTW, in-hospital mortality (20.2 ± 10.8% vs 32.3 ± 4.3%; $P = .001$) was greater in the <5 ARR group compared to the ≥5 ARR group, with no significant difference in other post-operative complications, as shown in Table E5. In our centers, low-volume surgeons perform dissections much more frequently, in addition to urgent/emergent cases. These cases can include scenarios in which VSRR is not indicated in these more complicated patients and in fact could demonstrate the need for surgical expertise in this cohort.

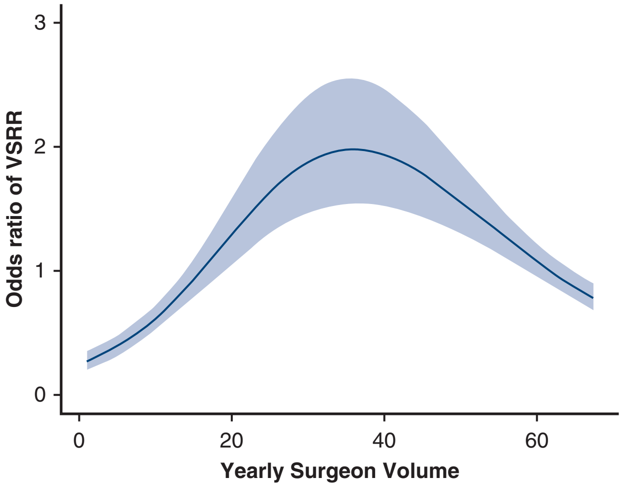

FIGURE E1. Cubic spline of odds ratio (with 95% confidence interval) of undergoing valve-sparing root replacement versus yearly surgeon volume. *VSRR*, Valve-sparing root replacement.

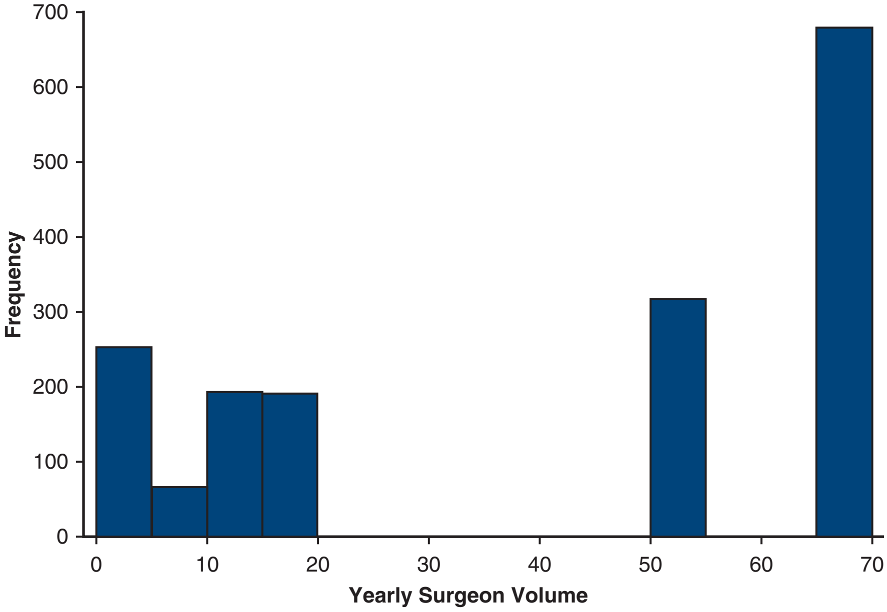

FIGURE E2. Histogram of surgeon volume distribution.

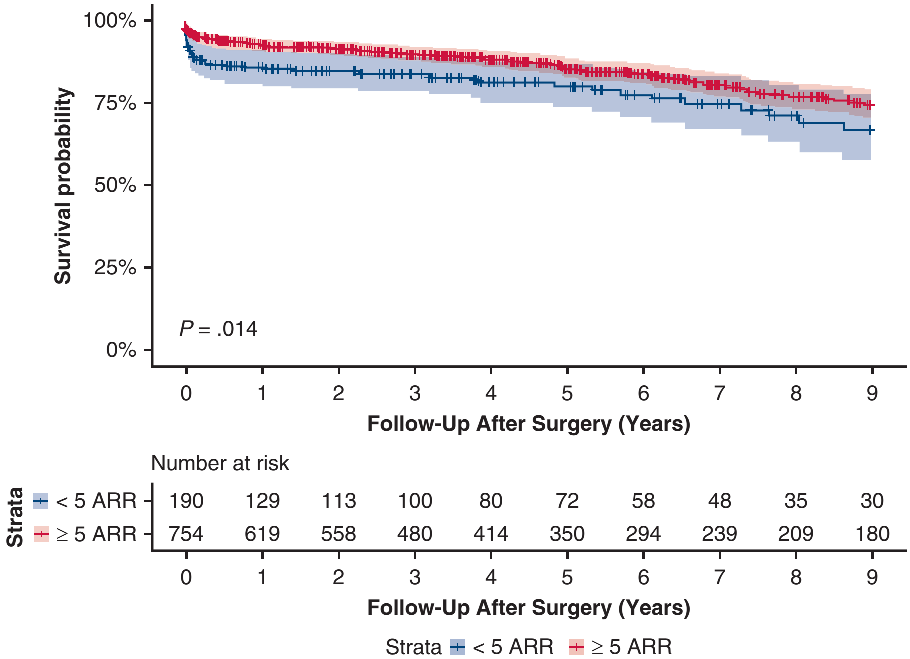

FIGURE E3. Kaplan-Meier curve (with 95% confidence interval) of inverse probability treatment weighting–balanced cohort among patients (rounded to the nearest whole number) who underwent valve-sparing root replacement operated on by <5 aortic root replacement (*ARR*) surgeons or ≥5 ARR surgeons.

TABLE E1. Demographics of the patient subgroup who underwent VSRR, overall and stratified by annual surgeon volume

Characteristic	Overall	<5 ARRs	≥5 ARRs	*P* value
Number	753	62	691	
Age, y, median (IQR)	51 (39, 61)	52 (37, 60)	51 (39, 61)	.79
Female sex, n (%)	126 (16.7)	10 (16.1)	116 (16.8)	1.00
BMI, median (IQR)	27.7 (24.6-31.5)	27.8 (25.2-30.8)	27.7 (24.5-31.6)	.62
CKD, n (%)	79 (10.5)	7 (11.3)	72 (10.4)	1.00
DM, n (%)	61 (8.1)	5 (8.1)	56 (8.1)	1.00
HTN, n (%)	516 (68.5)	40 (64.5)	476 (68.9)	.57
Surgical indication, n (%)				.71
Aneurysm	684 (90.8)	55 (88.7)	629 (91.0)	
Dissection	69 (9.2)	7 (11.3)	62 (9.0)	
Dyslipidemia, n (%)	341 (45.3)	28 (45.2)	313 (45.3)	1.00
CVD, n (%)	34 (4.5)	4 (6.5)	30 (4.3)	.66
PVD, n (%)	36 (4.8)	0 (0.0)	36 (5.2)	.13
Connective tissue disease, n (%)	79 (10.9)	8 (14.0)	71 (10.7)	.57
Bicuspid AV, n (%)	174 (23.1)	12 (19.4)	162 (23.4)	.57
Moderate/severe AI, n (%)	355 (47.1)	35 (56.5)	320 (46.3)	.16
Previous MI, n (%)	18 (4.6)	1 (4.8)	17 (4.6)	1.00
Reoperation, n (%)	58 (7.7)	4 (6.5)	54 (7.8)	1.00
LVEF, %, median (IQR)	55 (55-60)	55 (55-60)	55 (54-60)	.42

VSRR, Valve-sparing root replacement; *ARR*, aortic root replacement; *IQR*, interquartile range; *BMI*, body mass index; *CKD*, chronic kidney disease; *DM*, diabetes mellitus; *HTN*, hypertension; *CVD*, cerebrovascular disease; *PVD*, peripheral vascular disease; *AV*, aortic valve; *AI*, aortic insufficiency; *MI*, myocardial infarction; *LVEF*, left ventricular ejection fraction.

TABLE E2. Operative characteristics of the patient subgroup who underwent VSRR, overall and stratified by annual surgeon volume

Characteristic	Overall	<5 ARRs	≥5 ARRs	*P* value
Number	753	62	691	
Concomitant aortic procedure, n (%)				.03
Hemiarch	257 (34.1)	15 (24.2)	242 (35.0)	
Partial/total arch	79 (10.5)	3 (4.8)	76 (11.0)	
Concomitant MV procedure, n (%)	30 (4.0)	1 (1.6)	29 (4.2)	.51
Concomitant CABG, n (%)	89 (11.8)	9 (14.5)	80 (11.6)	.63
Bypass time, min, median (IQR)	193 (144-236)	201 (174-229)	193 (141-238)	.16
Cross-clamp time, min, median (IQR)	168 (120-211)	170 (135-193)	167 (119-212)	.97
Circulatory arrest, n (%)	338 (44.9)	19 (30.6)	319 (46.2)	.03

VSRR, Valve-sparing root replacement; *ARR*, aortic root replacement; *MV*, mitral valve; *CABG*, coronary artery bypass graft; *IQR*, interquartile range.

TABLE E3. Univariable logistic regression for undergoing VSRR versus non-VSRR

Variable	OR (95% CI)	*P* value
Age	0.95 (0.95-0.96)	<.001
Female sex	1.15 (0.88-1.49)	.31
CKD	0.37 (0.28-0.49)	<.001
DM	0.57 (0.41-0.79)	<.001
HTN	0.50 (0.40-0.62)	<.001
Dissection	0.63 (0.46-0.86)	.003
Dyslipidemia	0.61 (0.50-0.74)	<.001
CVD	0.45 (0.30-0.67)	<.001
Bicuspid AV	0.84 (0.68-1.06)	.05
Moderate/severe AI	0.23 (0.19-0.29)	<.001
Reoperation	0.48 (0.35-0.66)	<.001
LVEF	1.04 (1.03-1.05)	<.001
Concomitant arch replacement	0.64 (0.53-0.77)	<.001
Concomitant MV procedure	0.63 (0.40-0.98)	.04
Concomitant CABG	0.49 (0.37-0.64)	<.001
≥5 ARRs	2.76 (2.05-3.77)	<.001

VSRR, Valve-sparing root replacement; *OR*, odds ratio; *CI*, confidence interval; *CKD*, chronic kidney disease; *DM*, diabetes mellitus; *HTN*, hypertension; *CVD*, cardiovascular disease; *AV*, aortic valve; *AI*, aortic insufficiency; *LVEF*, left ventricular ejection fraction; *MV*, mitral valve; *CABG*, coronary artery bypass graft; *ARR*, aortic root replacement.

TABLE E4. Demographics of patients who underwent ARR with CVC after IPTW match between <5 ARR surgeons and ≥5 ARR surgeons

Characteristic	<5 ARRs	≥5 ARRs	*P* value	SMD
Number	185.9	752.5		
Age, y, median (IQR)	60 (50-68)	61 (50-70)	.63	0.038
Female sex, n (%)	26.3 (14.1)	111.6 (14.8)	.82	0.020
BMI, median (IQR)	28.5 (24.5-32.3)	27.8 (24.7-31.1)	.20	0.016
DM (%)	23.5 (12.6)	99.7 (13.3)	.84	0.018
CKD (%)	44.1 (23.7)	183.3 (24.4)	.87	0.014
HTN (%)	155.1 (83.4)	614.4 (81.6)	.60	0.047
CVD (%)	18.2 (9.8)	71.1 (9.4)	.89	0.011
Reoperation (%)	27.0 (14.5)	113.7 (15.1)	.84	0.017
Dissection (%)	27.4 (14.7)	103.8 (13.8)	.71	0.027
Dyslipidemia (%)	106.0 (57.0)	435.6 (57.9)	.83	0.018
Connective tissue disease (%)	3.9 (2.1)	16.5 (2.2)	.93	0.008
Moderate/severe AI (%)	145.7 (78.4)	596.8 (79.3)	.79	0.023
LVEF, %, median (IQR)	55 (48-58)	55 (48-60)	.84	0.020

ARR, Aortic root replacement; *CVC*, composite valved conduit; *IPTW*, inverse probability treatment weighting; *IQR*, interquartile range; *BMI*, body mass index; *DM*, diabetes mellitus; *CKD*, chronic kidney disease; *HTN*, hypertension; *CVD*, cerebrovascular disease; *LVEF*, left ventricular ejection fraction.

TABLE E5. Results of IPTW among patients who underwent ARR with CVC comparing <5 ARR and ≥5 ARR surgeons

Variable	<5 ARRs	≥5 ARRs	*P* value
Number	185.9	752.5	
In-hospital mortality (%)	20.2 (10.8)	32.3 (4.3)	.001
Stroke (%)	13.4 (7.2)	28.6 (3.8)	.05
Renal failure (%)	22.8 (12.3)	67.5 (9.0)	.19
Postoperative dialysis (%)	11.1 (6.0)	41.6 (5.5)	.81
Respiratory failure (%)	49.5 (26.6)	168.7 (22.4)	.23
Reoperation for bleeding (%)	17.5 (9.4)	68.8 (9.1)	.92

IPTW, Inverse probability treatment weighting; *ARR*, aortic root replacement; *CVC*, composite valved conduit.

TABLE E6. Demographics of patients who underwent VSRR after IPTW match between <5 ARR and ≥15 ARR surgeons

Characteristic	<5 ARRs	≥15 ARRs	*P* value	SMD
Number	59.48	626.91		
Age, y, median (IQR)	52 (37-60)	50 (39-61)	.90	0.008
Female sex (%)	9.8 (16.6)	104.6 (16.7)	.98	0.004
BMI, median (IQR)	27.6 (25.3-30.7)	27.6 (24.5-31.6)	.67	0.001
DM (%)	5.0 (8.3)	51.1 (8.1)	.96	0.007
CKD (%)	6.5 (10.9)	65.5 (10.4)	.92	0.013
HTN (%)	40.0 (67.2)	430.4 (68.7)	.81	0.031
CVD (%)	2.9 (4.9)	28.1 (4.5)	.86	0.021
Reoperation (%)	4.2 (7.0)	49.2 (7.8)	.82	0.032
Dissection (%)	7.2 (12.2)	59.3 (9.5)	.51	0.087
Dyslipidemia (%)	26.3 (44.3)	285.6 (45.6)	.85	0.026
Connective tissue disease (%)	6.6 (11.1)	69.0 (11.0)	.97	0.004
Moderate/severe AI (%)	29.9 (50.3)	294.8 (47.0)	.63	0.066
LVEF, %, median (IQR)	55 (55-60)	55 (54-60)	.86	0.012

VSRR, Valve-sparing root replacement; *IPTW*, inverse probability treatment weighting; *ARR*, aortic root replacement; *SMD*, standardized mean difference; *IQR*, interquartile range; *BMI*, body mass index; *DM*, diabetes mellitus; *CKD*, chronic kidney disease; *HTN*, hypertension; *CVD*, cerebrovascular disease; *AI*, aortic insufficiency; *LVEF*, left ventricular ejection fraction.

TABLE E7. Results of IPTW in patients who underwent VSRR comparing <5 ARR and ≥15 ARR surgeons

Variable	<5 ARRs	≥15 ARRs	*P* value
Number	59.5	626.9	
In-hospital mortality (%)	0.7 (1.2)	9.1 (1.5)	.875
Stroke (%)	0.7 (1.2)	11.2 (1.8)	.721
Renal failure (%)	1.9 (3.2)	25.0 (4.0)	.759
Postoperative dialysis (%)	0.7 (1.2)	16.1 (2.6)	.462
Respiratory failure (%)	8.4 (14.1)	71.4 (11.4)	.549
Reoperation for bleeding (%)	5.2 (8.7)	27.2 (4.3)	.142
Postoperative TEE AI (%)			.280
None/trace	23.9 (72.6)	452.8 (84.4)	
Mild	8.3 (25.1)	72.7 (13.6)	
Moderate	0.7 (2.2)	10.1 (1.9)	
Severe	0.0 (0.0)	1.0 (0.2)	
Predischarge TTE AI (%)			.98
None/trace	47.5 (87.1)	525.3 (87.4)	
Mild	6.2 (11.5)	68.6 (11.4)	
Moderate	0.8 (1.5)	7.0 (1.2)	

IPTW, Inverse probability treatment weighting; *VSRR*, valve-sparing root replacement; *ARR*, aortic root replacement; *TEE*, transesophageal echocardiography; *AI*, aortic insufficiency; *TTE*, transthoracic echocardiography.