The fate of residual aortic regurgitation after ascending aorta replacement in type A aortic dissection

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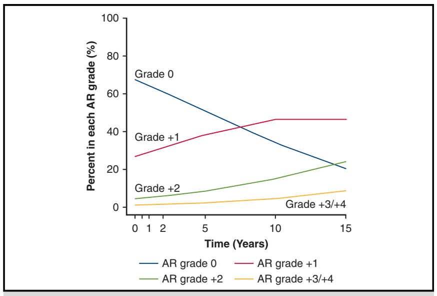
ABSTRACT

Objective: This study aimed to evaluate the changes in postoperative aortic regurgitation (AR) and determine the predictors of significant AR and root reoperation after ascending aortic replacement (AAR) in patients with acute type A aortic dissection.

Methods: From January 1995 to December 2017, 271 consecutive patients underwent valve/root-preserving AAR (n = 225) and root replacement (n = 46). AR grade trend over time was analyzed by the ordinal mixed-effects model. Significant AR was defined as AR grade ≥3+ during the follow-up period. Predischarge and follow-up echocardiograms were obtained in 95.6% and 88.8% of enrolled patients, respectively.

Results: At predischarge, postoperative ≥2+ AR was present in 20 (9.3%) and 1 (2.3%) patients in the AAR and root replacement groups, respectively. With increasing time after surgery, the grade of AR increased. At 10 years, 4.6% of patients had developed 3+ or 4+ AR. Considering death as the competing risk, the 10-year cumulative incidence of significant AR was significantly higher in the AAR than in the root replacement group (12.3% vs 2.2%; *P* = .047). The risk of root reoperation at 10 years was not different between the groups (*P* = .118). On Cox analysis, preoperative ≥3+ AR (*P* = .002), postoperative ≥2+ AR (*P* = .040), and false to true lumen ratio (*P* = .005) were associated predictors of significant AR.

Conclusions: Although valve/root-preserving AAR demonstrated reasonable long-term outcomes when compared with root replacement, preoperative ≥3+ AR, postoperative ≥2+ AR, and high false to true lumen ratio significantly increased the risk of significant AR. Therefore, careful echocardiographic surveillance may be warranted in patients with postoperative ≥2+ AR and small true lumen. (J Thorac Cardiovasc Surg 2020;160:1421-30)



With increasing time after ascending aortic replacement, the AR grade increases.

CENTRAL MESSAGE

Higher preoperative and postoperative AR grades and high false to true lumen ratio increased the significant AR risk in patients undergoing AAR with valve/root preservation for type A aortic dissection.

PERSPECTIVE

Although valve/root-preserving AAR in AAAD showed acceptable surgical outcomes, higher preoperative and postoperative AR grades increased significant AR risk. A high postoperative FL to TL ratio also affected significant AR; therefore, both efforts to reduce the pressurized FL and careful echocardiogram surveillance may be warranted in patients with postoperative ≥2+ AR and small TL.

See Commentaries on pages 1431 and 1432.

Despite improvements in surgical strategies and perioperative management over many years, acute type A aortic dissection (AAAD) continues to have a considerably high mortality rate, ranging from 11% to 26%.[1-3] A major concern for reducing the operative risk in patients with AAAD is determining the extent of resection according to

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Abbreviations and Acronyms

AAAD	= acute type A aortic dissection
AAR	= ascending aortic replacement
AR	= aortic regurgitation
ASCP	= antegrade selective cerebral perfusion
CT	= computed tomography
FL	= false lumen
MFS	= Marfan syndrome
RR	= root replacement
TL	= true lumen
TEE	= transesophageal echocardiogram

the location of the lesion and extent of the aortic involvement. Because the extension of the dissection flap into the aortic root often causes aortic regurgitation (AR) to a varying degree,[3-5] an appropriate surgical approach is important. Ascending aortic replacement (AAR) with preservation of the root and valve is the most common approach in emergency settings.[6,7] However, because the dissected wall remains in the root, this procedure may result in recurrent AR or root dilatation, and subsequent root and/or valve reoperation may be required.[8]

Some researchers have recently reported that extensive root surgery, such as root repair and replacement, by an experienced aortic surgeon was not associated with an increase in in-hospital mortality.[6,9] However, the optimal strategy for AAAD remains controversial, and there are limited reports on predictors of significant AR and reoperation. Thus, we aimed to evaluate changes in postoperative AR and to determine predictors of significant AR after AAR with valve/root preservation in patients with AAAD.

METHODS

Patient Selection

From January 1995 to December 2017, 340 consecutive patients with AAAD underwent emergency surgery at the Severance Cardiovascular Hospital, Yonsei University College of Medicine. Patients who previously underwent aortic valve or root replacement (RR) or who underwent aortic surgery for iatrogenic or retrograde aortic dissection were excluded. Of all patients, 225 (83%) underwent AAR with valve/root preservation (AAR group) and 46 (17%) underwent RR (RR group) with composite valved graft (Bentall) or valve-sparing procedure (David). The population flowchart is shown in Figure 1.

Surgical Technique

All operations were performed on an emergency basis as soon as the diagnosis was confirmed. Standard cardiopulmonary bypass was begun based on antegrade selective cerebral perfusion (ASCP) and moderate systemic hypothermia (28°C). To establish cardiopulmonary bypass, right axillary and femoral artery cannulation was used for arterial inflow and the right atrium was used for venous drainage. Unilateral ASCP through the right axillary artery was initiated by clamping the innominate artery, and the ascending aorta was opened. Bilateral ASCP was performed when the regional brain oxygen saturation decreased to <50% with insertion of the cerebral perfusion catheter into the left carotid artery. The surgical procedure was determined based on the extent of aortic valve or root pathology, severity of AR, involvement of coronary artery through the dissected flap, and the patient's comorbidity. Indications for RR were extensive dissection of the sinuses or of the coronary artery or presence of both root dilatation >55 mm and severe AR. Aortic valve-sparing RR was performed when the root and valve leaflet maintained normal geometry. All other patients underwent AAR. Even in patients with severe AR preoperatively, AAR with aortic valve resuspension and obliteration of false lumen (FL) by applying the sandwich technique was performed when the root diameter was <55 mm.

Once distal anastomosis was first performed using 3-0 Prolene (Ethicon, Somerville, NJ) sutures after circulatory arrest, systemic perfusion through the side branch of the graft was restored. Next, proximal anastomosis was performed during the rewarming period. The dissected aortic layers were secured with a small amount of biologic glue to reapproximate the aortic wall, and reinforcement of the dissected wall was performed using inner and outer polytetrafluoroethylene felts at the level of the sinotubular junction. The graft was then sewn to the reconstructed aortic wall using 4-0 Prolene continuous sutures (Video 1).

Image Assessment and End Point

By computed tomography (CT), we measured the diameter of ascending aorta at the midascending aorta level of pulmonary artery bifurcation and the aortic root diameter at the level of sinus of Valsalva. In the proximal descending thoracic aorta, aortic true lumen (TL) and FL diameters at the level of pulmonary artery bifurcation were measured. The degree of AR was assessed by intraoperative transesophageal echocardiogram (TEE) and by follow-up transthoracic echocardiogram before and after discharge at least once. AR severity was classified as follows: 0 (none/trace), 1+ (mild), 2+ (moderate), 3+ (moderately severe), and 4+ (severe). The presence of coronary artery involvement was identified by TEE.

In this study, the primary end point was change in postoperative AR over time. Secondary end points were long-term outcomes including significant AR, root reoperation, and overall survival. Significant AR was defined as grade $\geq$3+ AR during the follow-up period, and root reoperation was defined as any surgical procedure for aortic root diameter >55 mm, pseudoaneurysm of the aortic root, or symptomatic severe AR. Early death was defined as death within 30 days postoperatively or during the in-hospital period.

Data Collection

Preoperative and perioperative data with clinical outcomes were prospectively collected from the cardiac and vascular research database and from the review of medical records. Survival data were collected through the Korea National Statistical Office database. Follow-up was complete for 100% of the patients with a mean duration of 8.6 ± 5.8 years. Most patients (95.6%) underwent postoperative echocardiogram within 8 days before discharge. At least 1 or more follow-up echocardiograms were obtained in 88.8% of the patients with a mean follow-up duration of 7.9 ± 6.1 years. Moreover, postoperative CT evaluation was performed within a mean of 12.5 days in 92.6% of patients before discharge.

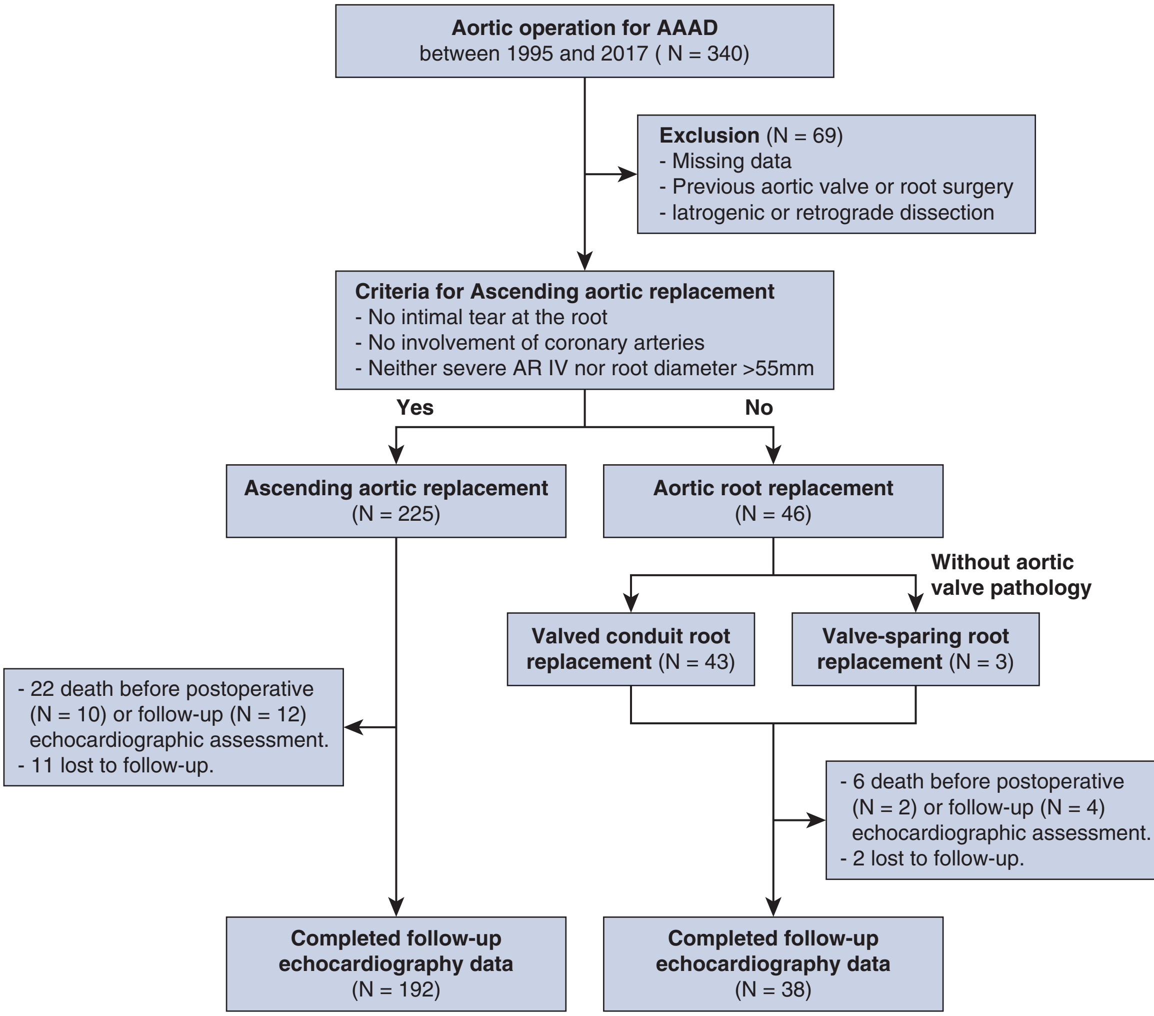


FIGURE 1. Summary flow diagram of the study population. In patients without echocardiographic data, early death was 9.8% for ascending replacement and 13.0% for root replacement. *AAAD*, Acute type A aortic dissection; *AR*, aortic regurgitation.

This study was approved by the Institutional Review Board of Yonsei University College of Medicine. Individual patient consent was waived because the study design was retrospective and there was no interference with patient treatment.

VIDEO 1. The aortic regurgitation grade decreased significantly after ascending aortic replacement in patients with acute type A aortic dissection with severe aortic regurgitation. Video available at: https://www.jtcvs.org/article/S0022-5223(20)30431-1/fulltext.

Statistical Analysis

Statistical analyses were performed using SPSS version 23.0 (IBM-SPSS Inc, Armonk, NY). All data are presented as mean ± standard deviation or frequencies and percentages. Comparisons between variables were performed using Student *t* test for continuous variables and the χ^2 or Fisher exact test for categorical variables. Cumulative incidence of significant AR or root reoperation with death as a competing risk was estimated by the nonparametric method using R software (cmprsk package; R Foundation for Statistical Computing, Vienna, Austria), and the 2 groups were compared using Gray test.[10] The patients who underwent reoperation were censored for AR. Ordinal mixed-effects models were used to assess the temporal trend of postoperative AR and to determine the predictors associated with AR grade over time. The model included the continuous variables of follow-up duration as a fixed effect and the subject effect as a random effect. The subject effects were assumed to be independent and have identical normal distribution (Tables E1 and E2).

Survival and freedom from significant AR were estimated by the Kaplan-Meier method with log-rank test. To determine the predictors of significant AR and root reoperation, the proportional hazards assumption was confirmed by Schoenfeld residuals test (Figure E1), but the assumption was not met. Thus, time-dependent Cox regression models were attempted. However, because there were few events for significant AR and root reoperation, we only presented the univariable analysis results. A receiver operating characteristic curve for the FL to TL ratio (FL:TL) was applied to measure the diagnostic accuracy over time (Figure E2) and to obtain the optimal cutoff value. All statistical tests were 2-tailed.

RESULTS

Demographic Characteristics and Intraoperative/Postoperative Data

The patient characteristics are summarized in Table 1. The AAR group was older and had a less proportion of preoperative 3+ or 4+ AR than the RR group (both P values < .05). In patients with unrecognized Marfan syndrome (MFS) at the time of surgery, 8 patients (3.6%) in the AAR group received a diagnosis of MFS postoperatively. These patients' clinical information is shown in Table E3. The mean diameters of the annulus and root were significantly smaller in the AAR group (both P values < .005).

As outlined in Table 2, the RR group tended to have a higher postoperative FL:TL (P = .058). Histograms of the FL:TL are presented in Figure E3. Moreover, concomitant coronary artery bypass grafting was more commonly performed in the RR group (19.6% vs 4.0%; P < .001) because of right coronary ostium involvement by the intimal flap. No significant difference was found in total circulatory arrest time. Postoperative outcomes were not different between the groups.

Among 41 patients without follow-up echocardiograms, early death was 9.8% (22 out of 225) for AAR and 13.0% (6 out of 46) for RR. Of these, 5 patients had ≥2+ AR on the intraoperative TEE and died of heart failure and bleeding. In the AAR group, 1 patient with 3+ AR underwent conversion to Bentall procedure but died of right ventricle dysfunction, 2 patients with 2+ AR refused reoperation, and 2 patients undergoing David procedure had 2+ or 3+ AR and failed to undergo reoperation due to high operative risk. Of the remaining 230, only 18 patients undergoing AAR had postoperative ≥2+ AR.

TABLE 1. Patients' baseline characteristics

Variable	Ascending aortic replacement (n = 225)	Root replacement (n = 46)	P value
Age (y)	60.2 ± 13.0	45.8 ± 15.6	<.001
Female	119 (52.9)	20 (43.5)	.245
Body surface area (m^2)	1.74 ± 0.22	1.80 ± 0.23	.095
Smoking	64 (28.4)	12 (26.1)	.746
Hypertension	173 (76.9)	26 (56.5)	.004
Diabetes mellitus	20 (8.9)	3 (6.5)	.776
Chronic renal failure	54 (24.0)	4 (8.7)	.021
Cerebrovascular accidents	19 (8.4)	5 (10.9)	.573
Chronic obstructive pulmonary disease	15 (6.7)	3 (6.5)	>.999
Peripheral arterial disease	7 (3.1)	0	.607
Coronary arterial disease	35 (15.6)	2 (4.3)	.043
Marfan syndrome	8 (3.6)	20 (43.5)	<.001
Cardiogenic shock	27 (12.0)	5 (10.9)	.829
Left ventricular ejection fraction (%)	62.0 ± 10.1	58.6 ± 13.0	.134
Aortic regurgitation grade			<.001
None	103 (45.8)	2 (4.3)	
1+	54 (24.0)	6 (13.0)	
2+	30 (13.3)	7 (15.2)	
3+	29 (12.9)	12 (26.1)	
4+	9 (4.0)	19 (41.3)	
Aortic annulus (mm)	24.0 ± 2.0	27.4 ± 6.0	.002
Sinus of Valsalva (mm)	40.9 ± 5.7	52.6 ± 14.9	<.001
Ascending aorta (mm)	53.8 ± 10.8	56.4 ± 15.0	.286
True lumen (mm)	19.8 ± 7.6	20.5 ± 9.4	.673
False lumen (mm)	17.2 ± 10.4	15.8 ± 10.8	.659
False/true lumen ratio	1.2 2 ± 1.14	1.36 ± 1.63	.638

Values are presented as mean ± standard deviation or n (%).

TABLE 2. Intraoperative and postoperative data

Variable	Ascending aortic replacement (n = 225)	Root replacement (n = 46)	*P* value
Intraoperative data			
Distal repair			.791
Hemiarch replacement	168 (74.7)	33 (71.7)	
Partial arch replacement	22 (9.8)	4 (8.7)	
Total arch replacement	35 (15.6)	9 (19.6)	
Concomitant procedures			
Coronary artery bypass graft	9 (4.0)	9 (19.6)	<.001
Mitral valve repair	3 (1.3)	5 (10.9)	.004
Tricuspid valve repair	3 (1.3)	1 (2.2)	.527
Cardiopulmonary bypass time (min)	201.3 ± 73.2	293.4 ± 110.9	<.001
Aortic crossclamp time (min)	118.2 ± 50.2	189.7 ± 76.4	<.001
Total circulatory arrest time (min)	44.5 ± 24.9	44.2 ± 37.9	.963
Postoperative data			
Reoperation for bleeding	23 (10.2)	8 (17.4)	.164
Stroke	19 (8.4)	2 (4.3)	.545
Prolonged ventilation (>72 h)	65 (28.9)	10 (21.7)	.323
Newly required dialysis	17 (7.6)	5 (10.9)	.551
In-hospital mortality	20 (8.9)	6 (13.0)	.410
Aortic regurgitation grade	n = 215	n = 44	.012
None	155 (72.1)	42 (95.5)	
1+	40 (18.6)	1 (2.3)	
2+	18 (8.4)	1 (2.3)	
3+	2 (0.9)	0	
Aortic annulus (mm)	24.1 ± 1.9	24.6 ± 2.6	.231
Sinotubular junction (mm)	31.6 ± 3.0	28.1 ± 3.1	<.001
True lumen (mm)	22.1 ± 8.0	19.2 ± 8.4	.055
False lumen (mm)	14.4 ± 10.4	17.9 ± 16.0	.214
False/true lumen ratio	0.94 ± 1.00	1.47 ± 1.53	.058

Values are presented as mean ± standard deviation or n (%).

Long-Term Outcomes

During follow-up, there were 21 late deaths (16 in AAR and 5 in RR). The 10-year overall survival was 82.1% ± 3.1% for AAR and 81.2% ± 6.1% for RR (log-rank $P = .756$) (Figure E4).

AR Grade Over Time and Significant AR

In the mixed-effects model, with increasing time after surgery, the incidence of higher AR grade increased (Figure 2). At 10 years, 15.1% of patients had developed 2+ AR and 4.6% of the patients had developed 3+ or 4+ AR. Longer duration, older age, and greater root diameter were significantly associated with increased AR grade over time. FL:TL, as calculated from the first postoperative CT findings, was also an associated predictor for AR grade over time (Table E2). Furthermore, severity of regurgitation increased rapidly with higher preoperative and postoperative AR grade. Figure 3, *A* and *B*, shows that patients with preoperative 3+ or 4+ AR and postoperative ≥2+ AR were more likely to have higher AR grade than patients without those conditions.

However, the RR group was excluded from this analysis. Because patients who underwent the Bentall procedure had no change in AR grade and only 3 patients underwent the David procedure, the data were too less for analysis. Considering death as the competing risk, the 10-year cumulative incidence of significant AR was higher in the AAR than in the RR group (12.3% vs 2.2%; $P = .047$) (Figure 4, *A*).

Root Reoperation

Thirteen patients underwent root reoperations using the Bentall procedure. The indications for reoperations were severe AR (n = 6), root dilatation with AR (n = 5), and pseudoaneurysm (n = 2). The 10-year cumulative incidence of root reoperation with death as the competing risk was 8.1% for AAR and 0% for RR, with no significant difference between the groups ($P = .118$) (Figure 4, *B*). Distal aortic reintervention included 13 arch replacements, 11 descending thoracic replacements, 7 thoracoabdominal replacements, and 20 stent grafts. Of these, 12 patients underwent 2 or more procedures.

Predictors for Significant AR and Root Reoperation

In the time-dependent Cox analyses, the associated predictors for significant AR were preoperative ≥3+ AR,

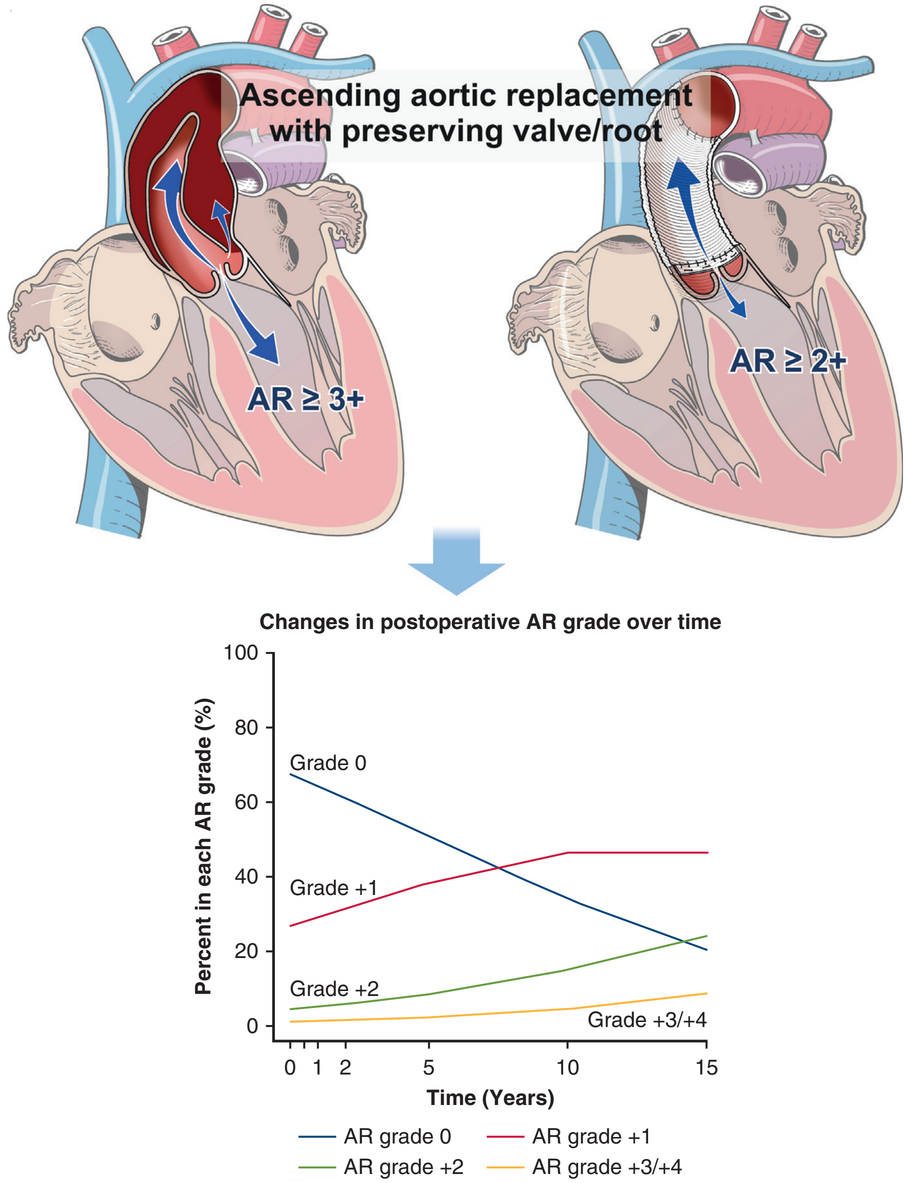


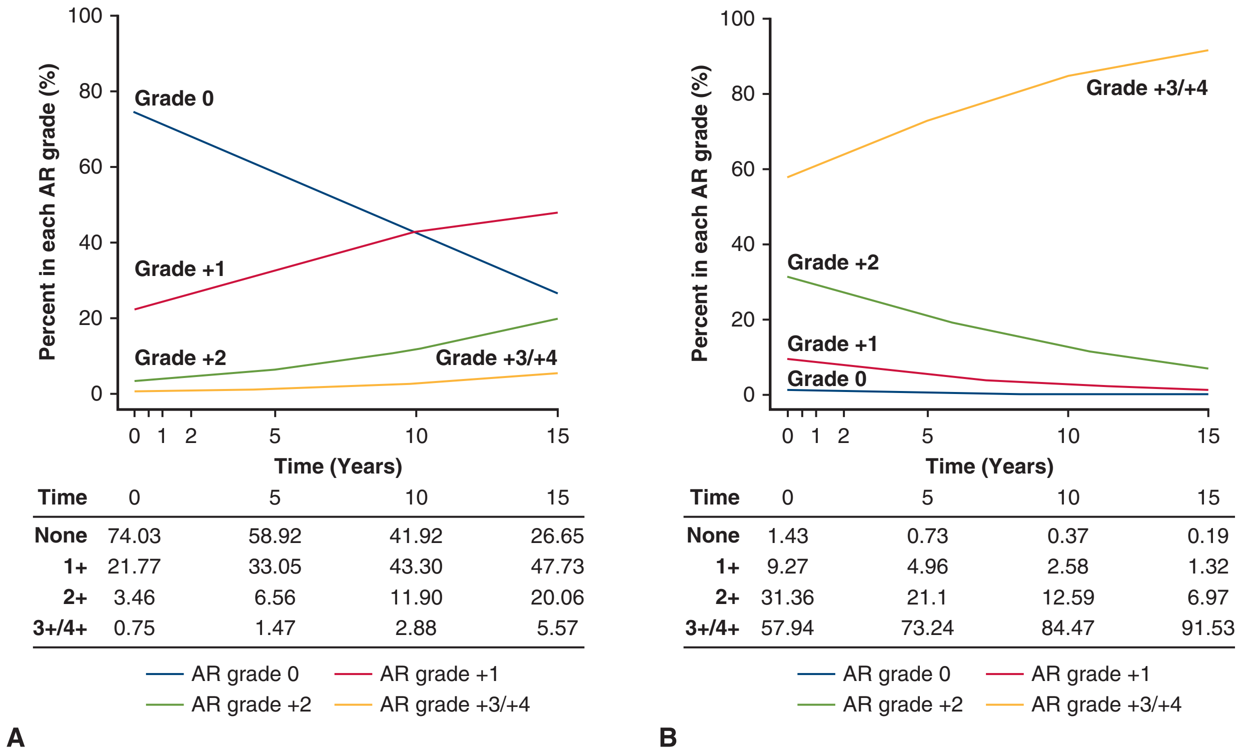
FIGURE 2. After surgery of ascending aortic replacement in patients with acute type A aortic dissection, high preoperative or postoperative aortic regurgitation (*AR*) is significantly associated with increased AR grade over time.

postoperative ≥2+ AR, and postoperative FL:TL (all *P* values <.05) (Table 3). The freedom from significant AR was significantly lower in patients with high preoperative or postoperative AR grade (Figure 5, *A* and *B*). When applying the optimal cutoff value for FL:TL, the 10-year freedom from significant AR was also lower in patients with a ratio ≥1.5 (65.1% ± 10.0% vs 95.6% ± 2.5%; *P* < .001) (Figure 5, *C* and *D*). Additionally, younger age and larger root were predictors of root reoperation.

DISCUSSION

In this study, the majority of patients with preoperative AR showed significant improvement after AAR with valve/root preservation. However, in some patients, the AR persisted postoperatively, and this factor affected significant AR. In addition, higher preoperative and postoperative AR grade and high FL:TL were predictors of significant AR and AR grade over time.

Although refinements in the surgical techniques and perioperative care over time have been made for patients with AAAD, the risk of mortality and morbidity following emergency surgery remains high. To prevent aortic rupture and to keep the patient alive, central repair through AAR with sinotubular reinforcement may be commonly performed, but this procedure has been reported to have a relative risk of late reoperation.[11,12] Meanwhile, more extensive



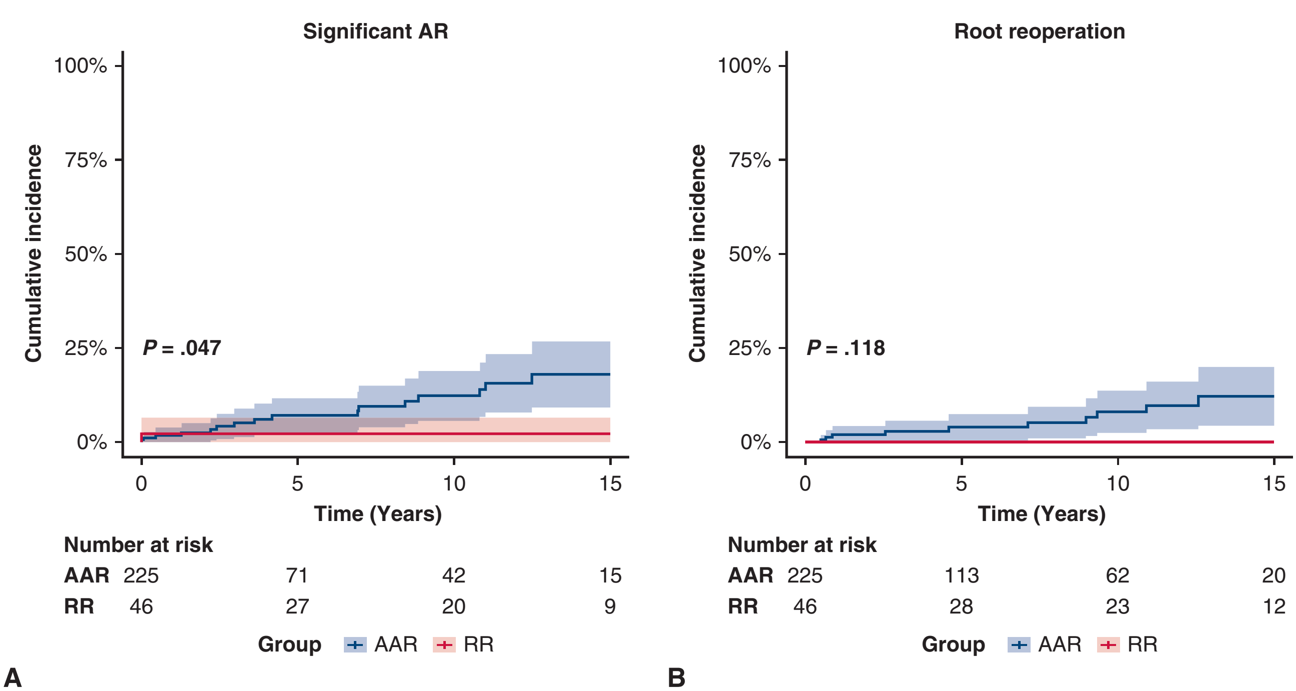
A

Time	0	5	10	15
None	74.03	58.92	41.92	26.65
1+	21.77	33.05	43.30	47.73
2+	3.46	6.56	11.90	20.06
3+/4+	0.75	1.47	2.88	5.57

B

Time	0	5	10	15
None	1.43	0.73	0.37	0.19
1+	9.27	4.96	2.58	1.32
2+	31.36	21.1	12.59	6.97
3+/4+	57.94	73.24	84.47	91.53

FIGURE 3. Changes in postoperative aortic regurgitation (*AR*) grade over time after adjusting for male patients of mean age with mean root diameter and false to true lumen ratio. A, Patients with both preoperative <3+ AR and postoperative <2+ AR. B, Patients with preoperative ≥3+ AR and postoperative ≥2+ AR.



A — Number at risk

	0	5	10	15
AAR	225	71	42	15
RR	46	27	20	9

B — Number at risk

	0	5	10	15
AAR	225	113	62	20
RR	46	28	23	12

FIGURE 4. Considering death as the competing risk, the cumulative incidence (A) for significant aortic regurgitation (*AR*) and (B) root reoperation (*RR*) between the groups. *AAR*, Ascending aortic replacement.

TABLE 3. Associated predictors for significant aortic regurgitation (AR) and root reoperation by Cox regression analysis

Variable	Hazard ratio (95% confidence interval)	*P* value
Significant AR		
Pre-AR grade ≥3+	7.024 (2.598-18.986)	<.001
Post-AR grade ≥2+	4.365 (1.376-13.846)	.002
False/true lumen ratio	2.221 (1.429-3.453)	<.001
Root reoperation		
Age (y)	0.908 (0.863-0.955)	<.001
Post-AR grade ≥2+	4.818 (1.227-18.922)	.024
Sinus of Valsalva	1.121 (1.071-1.173)	<.001
False/true lumen ratio	2.325 (1.406-3.844)	.001

AR, Aortic regurgitation.

aortic root surgeries such as root repair or replacement may prevent late aneurysm formation and recurrent dissection of the aortic root or worsening of the AR, but they remain controversial.[8,13] At our institute, most patients with AAAD undergo AAR with valve/root preservation, whereas patients with both root dilatation >55 mm and severe AR or those with existing intimal tear at the aortic root and coronary arteries are considered for RR.

In addition, we focused on the fate of untreated AR in patients with AAAD. Varying degrees of AR are caused by retrograde extension of the dissection, involvement of the sinus segment, and downward displacement of normal aortic leaflets into the left ventricle.[5] When there was no obvious valvular pathology, AAR with restoration of the integrity of valve competence was performed even in patients with preoperative severe AR, and postoperative AR was dramatically reduced in this study. However, in some cases, AR did not regress despite correction of the dissection and persisted postoperatively in 20 patients (9.3%). Paulis and colleagues[14] have reported that residual AR reflects insufficient adhesion and fixation of the dissected layers. Moreover, Luciani and colleagues[15] reported that the normal looking root and valve at the time of initial operation may be actually abnormal in patients who subsequently progress to AR. These findings are somewhat consistent with our results. Significant AR was observed during follow-up in 27.8% and 22.2% of patients who were postoperatively diagnosed with valvular pathology and connective tissue disease, respectively. These results imply that it is important to consider the patient-related factors when determining the initial surgical approach.

Although previous reports demonstrated preoperative severe AR as a risk factor for progressive AR,[16,17] it has not been reported exactly how the postoperative residual regurgitation changes during follow-up. Our results showed that the risk of significant AR increases when postoperative regurgitation remains. Therefore, we should keep in mind that if AR remains upon bypass weaning in the operating room or if there is residual ≥2+ AR upon predischarge transthoracic echocardiogram, AR may gradually proceed and the reoperation rate may increase. Additionally, if the life expectancy, surgical risk, and emergency status are acceptable, we highly recommend the extensive root surgery for reoperation. Careful echocardiographic surveillance to assess the aortic valvular function and efforts to reduce AR severity are also warranted.

In our findings, high preoperative and postoperative AR grades were identified as an associated predictor of significant AR, but the incidence of root events was low and distal reintervention was more common. High FL:TL was also an important risk factor for significant AR. The exact cause of these findings is unknown, but it is well known that pressurized FL in the descending thoracic aorta is a major cause of aortic dilatation.[18] In a recent study published by Suzuki and colleagues,[19] they measured FL and TL diameters on postoperative CT and reported that false lumen to true lumen index >1 was an important predictor of late proximal and distal reoperation. We believe that a high FL:TL may reflect unfavorable aortic remodeling because FL due to the residual dissected aorta remains patent, and then pressurized FL increases the afterload, which may have cause root dilatation or AR. Therefore, reintervention to FL, such as endovascular stent and reoperation on the distal aorta, and vasodilator therapy reducing aortic dilatation and afterload may help enhance the forward flow of TL.

Moreover, many factors that potentially affect late root reoperation following AAR include severity of AR, root dilatation, involvement of the coronary arteries, presence of known aortic diseases (eg, annuloectasia or MFS), and dissection of all the aortic sinuses.[6,12,20] In this study, young age and root dilatation were associated with increases in proximal reoperation rates. Similar to those of previously reported studies,[6,11] these results may be explained by the fact that extensive root surgery in young patients with a large aortic root may reduce the risk of future root reoperation.

This study has several limitations. First, it was a single-center retrospective study. Although only AAAD patients were enrolled in this study, the presence of selection bias cannot be ruled out because the characteristics of the 2 groups (including incidence of MFS, age, and FL:TL) were biologically different. It is difficult to generalize conclusions about the clinical outcome by surgical intervention alone. Second, although some patients had long-term follow-up, only 192 patients had echocardiographic data available for analysis. The relatively small sample size of patients undergoing RR was insufficient to ensure statistically robust inferences; therefore, the reoperation prevalence between the groups may have been underestimated. Third, due to the very small number of events, we presented only the time-dependent univariable

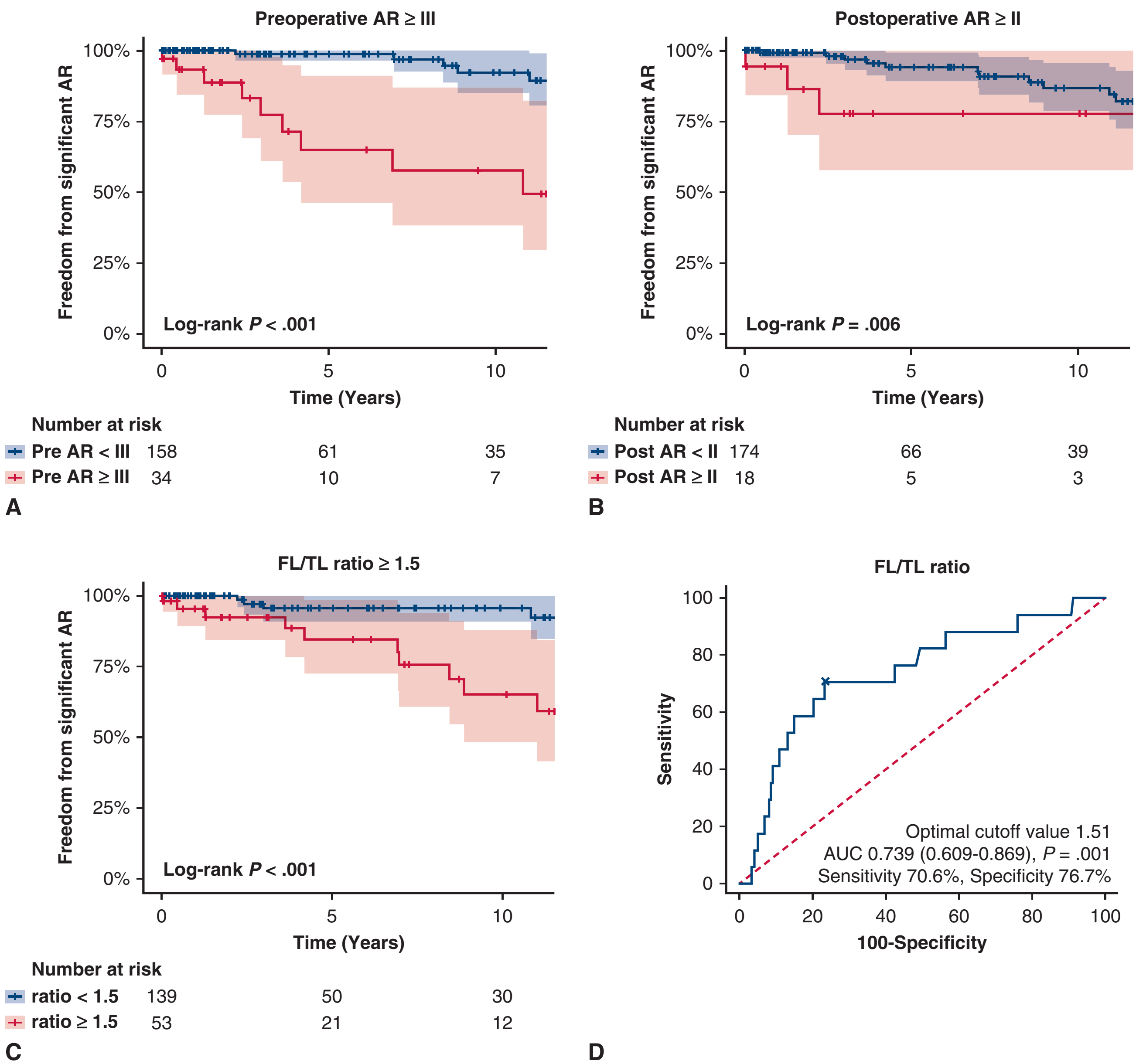


FIGURE 5. Kaplan-Meier curves comparing freedom from significant aortic regurgitation (*AR*) according to (A) preoperative ≥3+ AR, (B) postoperative ≥2+ AR, and (C) ratio ≥1.5. D, Receiver operating characteristic curve for false lumen to true lumen ratio (*FL/TL ratio*) as predictor of significant AR. The optimal cutoff value of the ratio was 1.51. *AUC*, Area under the curve.

Cox models because multivariable models were too unstable to identify predictors for significant AR and reoperation. A large-scale, prospective study is necessary to confirm our findings in the setting of emergency surgery. Finally, factors such as surgeons' experience, surgical strategies, and postoperative use of medication may have influenced the long-term outcomes. However, considering patient-specific and aortic pathologic factors, we believe that rapid judgment and choice of the appropriate surgical procedure are paramount to saving the lives of patients in an emergency situation.

CONCLUSIONS

In patients with AAAD, AAR with valve/root preservation showed good surgical outcomes. We found that preoperative 3+ or 4+ AR and postoperative ≥2+ AR were important risk factors for significant AR. Additionally, a high postoperative FL:TL can induce AR or root dilatation, which may be a predictor of significant AR. Therefore, both efforts to reduce the pressurized FL and careful echocardiographic surveillance to assess the aortic valve function may be warranted in patients with postoperative ≥2+ AR and small TL.

ADULT

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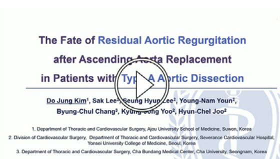

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: aortic dissection, aortic valve insufficiency

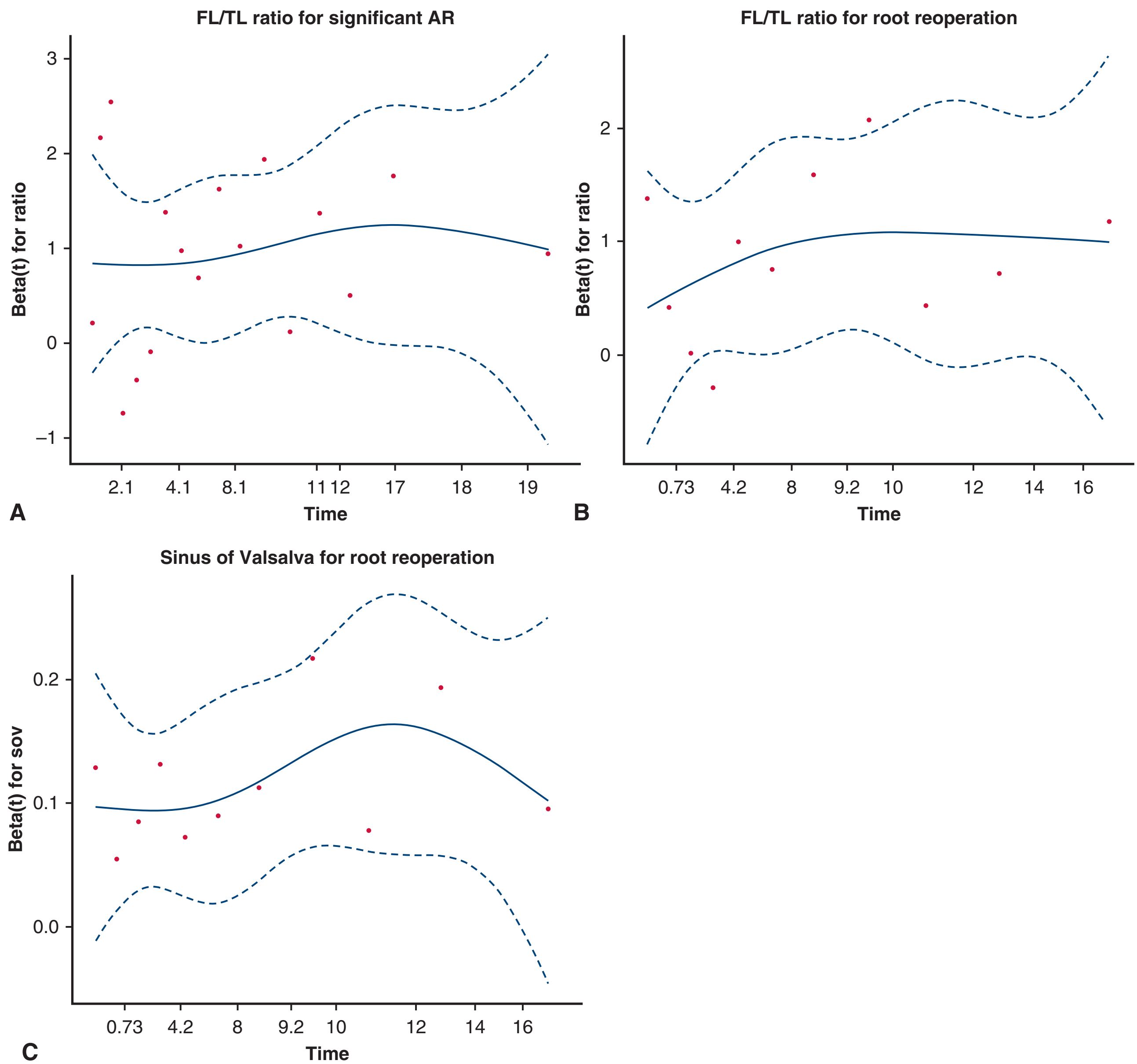

FIGURE E1. A, Cox proportional hazards (PH) assumptions of postoperative false lumen to true lumen ratio (*FL/TL ratio*) and diameter of sinus of Valsalva for significant aortic regurgitation (*AR*). B and C, Assumptions for the root reoperation were confirmed by Schoenfeld residuals test. Based on the graphical inspection, a non-0 slope is an indication of a violation of the PH assumption for the covariates.

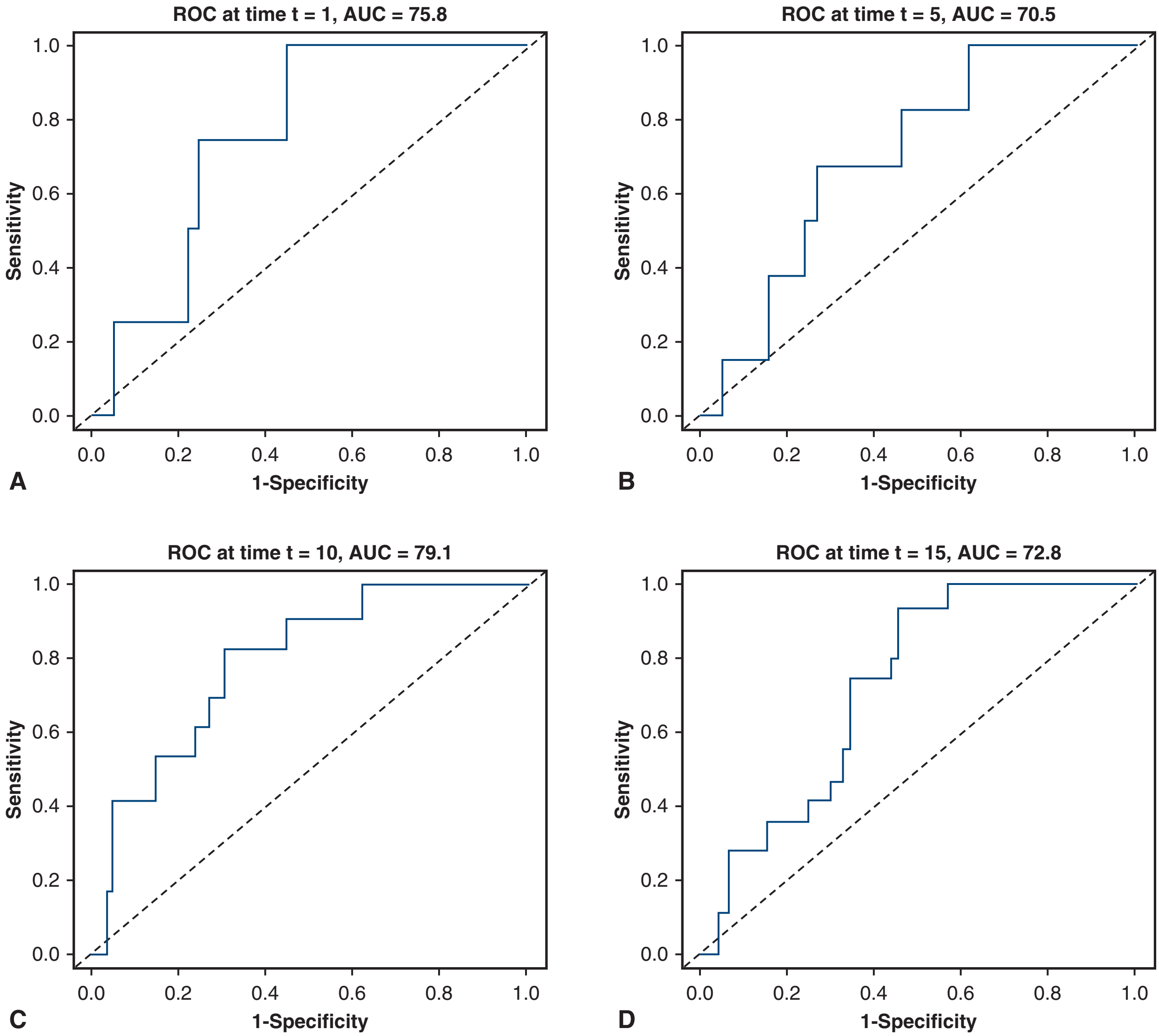

FIGURE E2. Time-dependent receiver operating characteristics (*ROC*) analyses of postoperative false lumen to true lumen ratio (FL/TL ratio) for significant aortic regurgitation (AR). A, At 1 year, area under the curve (*AUC*) of 0.758. B, At 5 years, AUC of 0.705. C, At 10 years, AUC of 0.791. D, At 15 years, AUC of 0.728. These results suggest that the FL/TL ratio is a reliable marker for predicting significant AR at each time point.

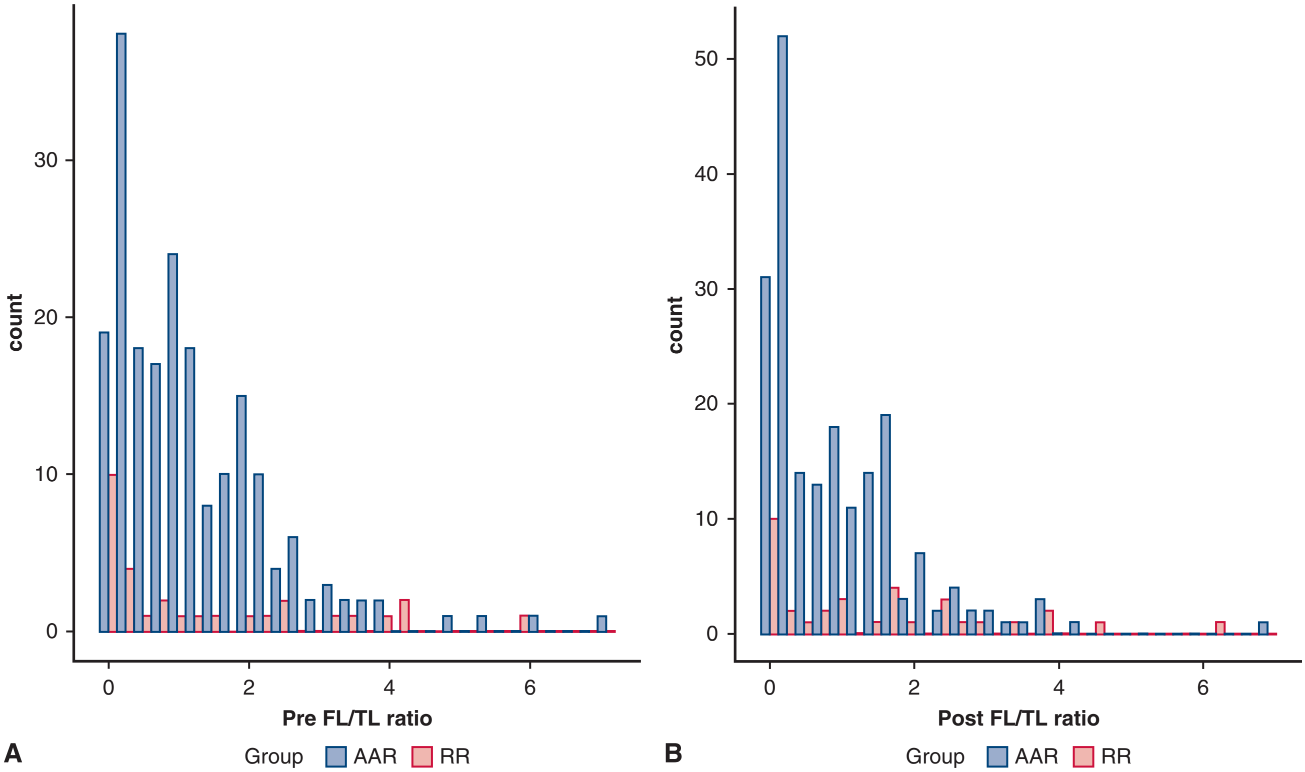

FIGURE E3. Histogram of the preoperative (A) and postoperative (B) false lumen to true lumen ratios (*FL/TL ratios*) in the 2 groups. The postoperative ratio in the ascending aortic replacement (*AAR*) group was lower than that in the root replacement (*RR*) group, whereas the preoperative ratio was similar in both groups.

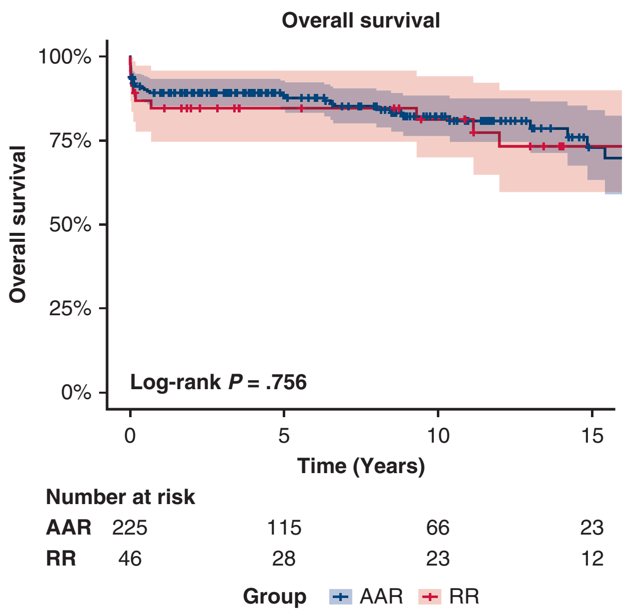

FIGURE E4. Kaplan-Meier survival curves for the ascending aortic replacement (*AAR*) versus root replacement (*RR*) group at 15 years. There was no significant difference between the AAR and RR groups. Shaded area represents 95% confidence interval.

TABLE E1. Change over time in postoperative aortic regurgitation grade by ordinal mixed-effects model*

Correlate	Coefficient ± standard error	*P* value
Duration, y	0.139 ± 0.023	<.001
Intercept 0	0.729 ± 0.198	<.001
Intercept 1	2.805 ± 0.244	<.001
Intercept 2	4.437 ± 0.296	<.001

*This model includes the variable of follow-up duration as a fixed effect and a random intercept. With increased follow-up duration, a higher aortic regurgitation grade ($\exp^{0.139} = 1.149$) was highly possible.

TABLE E2. Change over time in postoperative aortic regurgitation (AR) grade by multinomial ordinal mixed-effects model

	Unadjusted		Adjusted†	
Variable*	Coefficient ± standard error	*P* value	Coefficient ± standard error	*P* value
Duration (y)	0.139 ± 0.023	<.001	0.137 ± 0.022	<.001
Age	0.033 ± 0.013	.013	0.034 ± 0.013	.008
Male sex	–0.718 ± 0.336	.033	–0.420 ± 0.303	.165
Hypertension	–0.069 ± 0.399	.863		
Marfan syndrome	0.499 ± 0.896	.578		
Pre-AR grade ≥3+	3.019 ± 0.388	<.001	2.297 ± 0.350	<.001
Post-AR grade ≥2+	3.870 ± 0.478	<.001	2.982 ± 0.446	<.001
Sinus of Valsalva	0.125 ± 0.027	<.001	0.082 ± 0.024	.001
False/true lumen ratio	0.006 ± 0.004	.098	0.284 ± 0.148	.055

*In the unadjusted univariate model, a variable with $P < .1$ was included in the adjusted multivariate model. †The adjusted multivariate model showed that the predictors for increasing AR grade over time was longer duration, older age, higher preoperative AR (grade ≥3+), higher postoperative AR (grade ≥2+), and higher root diameter. The false to true lumen ratio was also an associated predictor for increasing AR grade over time.

TABLE E3. Clinical information of patients who were diagnosed with Marfan syndrome after ascending aortic replacement surgery

Patient	Sex/age (y)	Aortic root diameter (mm)			AR grade			Time to progressive AR (y)*	Time to root reoperation (y)†	Indication for root reoperation
		Pre	Post	Last	Pre	Post	Last			
1	Female/32	48.0	45.0	93.6	0	0	3	17.0	17.1	Severe AR, root aneurysm
2	Male/24	57.0	50.3	92.0	0	0	4	8.9	9.0	Severe AR, root aneurysm
3	Male/34	49.3	46.0	64.0	3	0	3	6.9	7.1	Severe AR, root aneurysm
4	Female/34	42.5	39.0	56.0	4	0	4	10.8	10.9	Severe AR, annuloaortic ectasia
5	Female/54	54.7	41.0	55.0	3	2	3	2.4	2.6	Severe AR, annuloaortic ectasia
6	Female/30	36.4	34.5	No data	0	0	0			
7	Male/36	50.2	47.9	57.0	0	0	0			
8	Male/38	48.4	44.0	44.0	0	0	0		0.9	Proximal pseudoaneurysm

AR, Aortic regurgitation. *Time gap between primary ascending aortic replacement surgery and progressive AR (grade $\geq$3+). †Time gap between primary ascending aortic replacement surgery and root reoperation.