The fate of aortic root and aortic regurgitation after supracoronary ascending aortic replacement for acute type A aortic dissection

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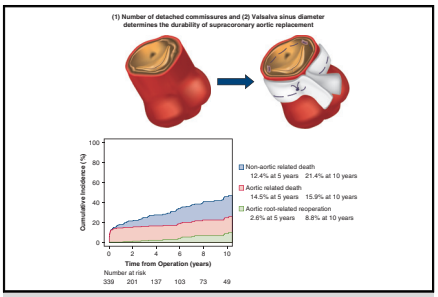
ABSTRACT

Background: The aim of this study was to evaluate the fate of the preserved aortic root after supracoronary aortic replacement for acute type A aortic dissection.

Methods: Between October 1999 and March 2018, 339 patients underwent supracoronary aortic replacement for acute type A aortic dissection at our institution. Late outcomes were evaluated, including overall survival, aortic-related death, and aortic root–related reoperation. The median follow-up was 3.7 years (1.4-8.4 years).

Results: Operative mortality was 46 patients (13.6%). The cumulative incidences at 5 years for aortic root–related reoperation, aortic-related death, and non–aortic related death were 2.5%, 14.5% and 12.4%, respectively. Multivariable Cox hazard regression analysis demonstrated greater sinus of Valsalva diameter and number of commissural detachments to be significant risk factors for a composite outcome consisting of aortic-related death or aortic root–related reoperation. Mixed-effects regression demonstrated that sinus of Valsalva diameter significantly increased with time ($P < .001$), and aortic regurgitation significantly worsened ($P < .001$).

Conclusions: Sinus of Valsalva diameter and commissural detachment were independent predictors of unfavorable outcomes after supracoronary aortic replacement. Close follow-up is particularly necessary for these patients, and aortic root replacement at the time of initial operation may lead to more favorable late outcomes. (J Thorac Cardiovasc Surg 2021;161:483-93)



Surgical schema of supracoronary aortic replacement and late outcomes.

Central Message

Sinus of Valsalva diameter and commissure detachment were independent risk factors for unfavorable aortic root outcomes.

Perspective

Sinus of Valsalva diameter and commissure detachment were independent predictors for unfavorable aortic root outcomes. Aortic root replacement may be recommended for patients with these risk factors. Periodic follow-up with computed tomography and echocardiography is particularly needed by these patients.

See Commentaries on pages 494, 495, and 496.

Surgical outcomes of open repair of acute type A aortic dissection (AAAD) have improved during the last 2 decades.[1,2] The primary goal of emergency surgery for AAAD is to save the life of the patient. Supracoronary ascending aortic replacement (SCR) is considered the standard surgical procedure for AAAD; however, hospital survivors may require additional aortic intervention for aortic root dilation or aggravation of aortic regurgitation (AR).[3-5]

Aortic root replacement (ARR) is another well-established strategy for AAAD, particularly in patients with severe disruption of the sinus of Valsalva or an aortic sinus diameter larger than 50 mm. Several recent studies

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Abbreviations and Acronyms

AAAD = acute type A aortic dissection
SCR = supracoronary ascending aortic replacement
AR = aortic regurgitation
ARR = aortic root replacement
VSRR = valve-sparing root replacement
CT = computed tomography
GRF = gelatin-resorcin-formalin
HR = hazard ratio
CI = confidence interval

have reported that aggressive ARR with the Bentall operation for AAAD prevented future aortic root reintervention without increasing in-hospital mortality.[6-8] The optimal surgical strategy in cases of moderate aortic root involvement, however, remains controversial. Composite valve graft replacement for patients with intact aortic cusps may result in the added the risk of anticoagulation required with mechanical valves or the risk of reoperation seen with bioprosthetic valves. Although our previous report demonstrated that valve-sparing root replacement (VSRR) could be performed with satisfactory mortality in selected patients,[9] its feasibility in emergency situations and long-term durability remains unclear.[10,11]

Differences in baseline and presenting patient characteristics make direct comparisons of these procedures challenging. Nevertheless, the identification of significant risk factors for adverse late outcomes and reintervention after SCR would provide new insights into the indications for ARR. In light of these controversies, our study evaluated the long-term outcomes of the preserved aortic root after SCR in patients with AAAD.

PATIENTS AND METHODS

Study Population

Between October 1999 and March 2018, a series of 380 patients underwent open aortic repair for AAAD at our institution. Patients who underwent concomitant ARR (n = 27) and 14 patients with connective tissue disease were excluded from the study. Thus 339 patients remained for analysis (Figures 1, E1, and E2).

The indications for ARR were as follows[9]: (1) aortic root aneurysm larger than 50 mm, or larger than 45 mm in patients younger than 50 years; (2) intimal tear in the aortic root; and (3) ruptured aortic root. SCR was indicated for patients with unstable hemodynamic status, metabolically significant end-organ malperfusion, poor cardiac function (ejection fraction <40%), or serious systemic diseases, as well as for elderly patients (Figure 2).

Follow-up data were obtained by clinical visit, telephone contact, or written correspondence. A common closing date was used. Follow-up was available for all but 9 patients. The median follow-up period was 3.7 years (1.4-8.4 years, last follow-up October 2018) and follow up rate was 96.9%. The study protocol was reviewed and approved by the institutional review board. An informed consent waiver was granted.

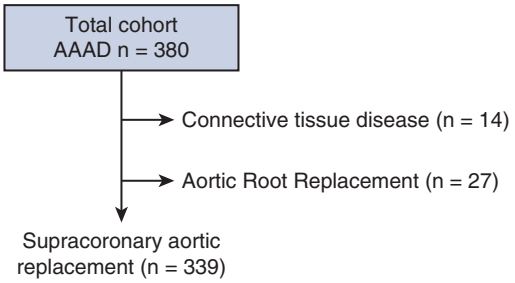


FIGURE 1. Study cohort. *AAAD*, Acute type A aortic dissection.

Definition of Clinical Outcomes

The Japanese guidelines for aortic dissection with thrombosed false lumen were used for diagnosis.[12] The number of detached commissures was assessed intraoperatively. Aortic root–related reoperation was defined as reoperative aortic surgery for dilation of the aortic root (>50 mm), pseudoaneurysm involving the aortic root, or greater than moderate AR.

We assessed the clinical outcomes and echocardiographic measurements during postoperative follow-up at 1 month and annually thereafter, when possible. Data at the time of first detection of AR were used. Valve insufficiency was graded as none or trivial (grade 0/1), mild (grade 2), moderate (grade 3), or severe (grade 4) according to the American Society of Echocardiography on integrating qualitative and semiquantitative assessments.[13]

A single, blinded observer was responsible for measuring all Valsalva sinus diameters, and all computed tomography (CT) data were measured with the Ziostation 2 (Ziosoft, Inc, Tokyo, Japan). The maximum diameter perpendicular to the longitudinal axis was measured as the distance between the outer borders of the root.

All study patients had CT follow-up, and the obtained measurements were used for the analysis. CT assessments were conducted before discharge (n = 281) and then at the 1-year follow-up (n = 227), 3-year follow-up (n = 196), 5-year follow-up (n = 143), 8-year follow-up (n = 102), and 10-year follow-up (n = 61) time points.

Surgical Procedures

The surgical details of this procedure have been previously reported[14] (Video 1). Hypothermic circulatory arrest was achieved at a tympanic temperature of less than 23°C and a rectal temperature of less than 30°C. Of note, our brain protection method shifted from retrograde cerebral perfusion to antegrade cerebral perfusion in 2002. If crossclamping was not possible during cooling, the distal aortic repair was performed first, followed by the proximal aortic repair. If the clamp site was free of thrombosis, the crossclamp was placed at the distal ascending aorta. If it was possible to crossclamp the proximal aorta, the proximal anastomosis was performed first, followed by the distal anastomosis.

The aorta was transected 1 cm distal to the sinotubular junction. Proximal re-approximation was performed using Teflon felt outside the adventitia with surgical adjuncts such as gelatin-resorcin-formalin (GRF) glue (MicroVal SA, Saint-Just Malmont, France) or BioGlue (CryoLife Inc, Kennesaw, Ga), inside the false lumen with a 4-0 polypropylene running suture. Commissural resuspension was performed with pledgeted sutures. We used GRF glue between 1999 and 2010, followed by a transition to the use of BioGlue in 2011. These surgical adjuncts were used in all but 14 patients.

After completion of the distal anastomosis, lower-body circulation was reinstituted, the patient was warmed, and the graft was anastomosed to the proximal aortic stump. Blood flow to the heart was then restored. The left subclavian artery, left common carotid artery, and innominate artery were reconstructed sequentially when necessary.

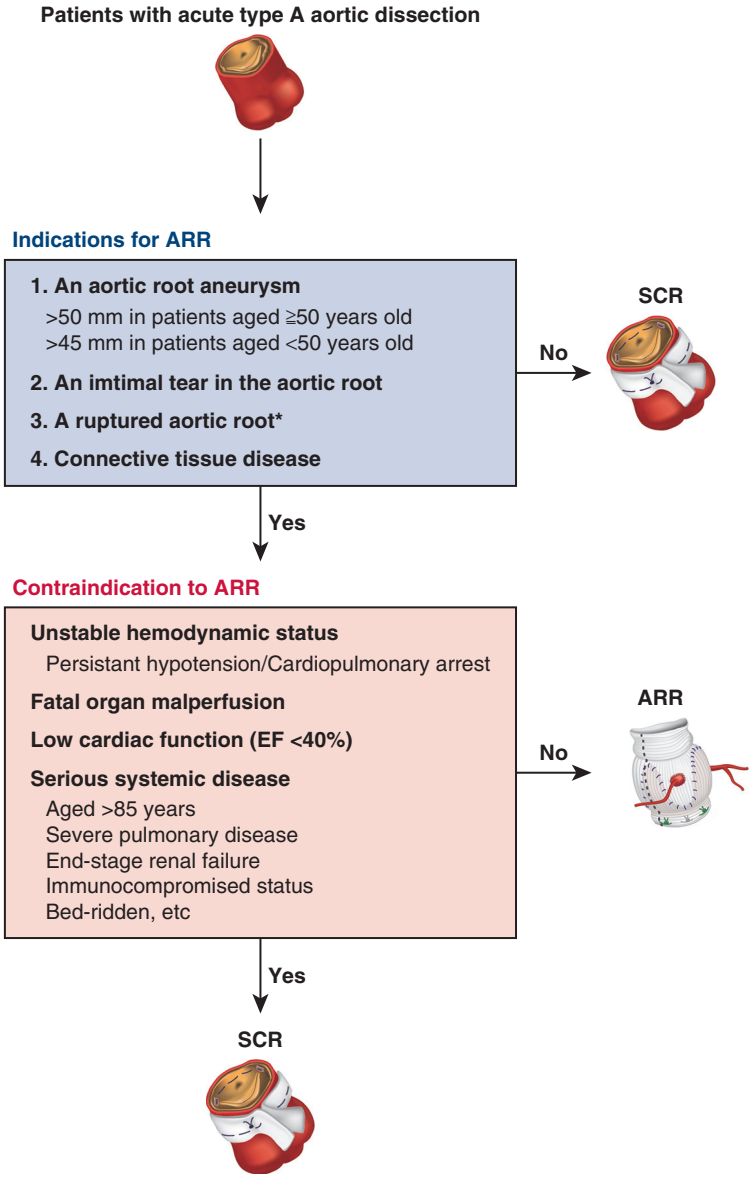
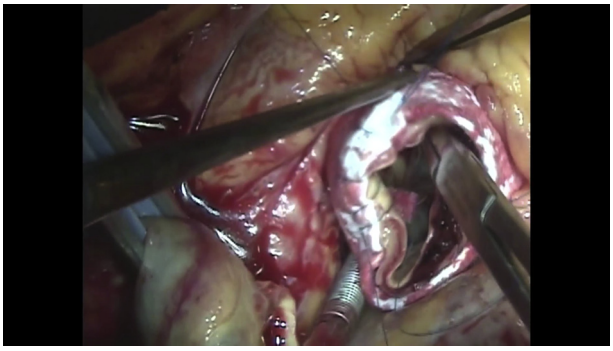


FIGURE 2. Indications for supracoronary aortic replacement (*SCR*) and aortic root replacement (*ARR*). In cases of aortic root rupture, ARR is indicated regardless of contraindications (*asterisk*). *EF*, Ejection fraction.

Statistical Analysis

All continuous variables are expressed as the mean ± SD or as the median with an interquartile range. Categorical variables are expressed as the number and percentage of patients. Categorical variables were analyzed by the χ^2 test. The assumption of normality of continuous data was tested with the Shapiro-Wilk test. When the assumption of normality was met, continuous variables were compared with the Student *t* test. The Mann-Whitney test was used for nonparametric variables.

The overall survivals were computed with the Kaplan-Meier methods and are expressed as the rate ± SE. The non–aortic related death, aortic-related death, and aortic root–related reoperation rate were estimated with the cumulative incidence function.[15,16] The composite outcomes for multivariable Cox regression analysis (n = 72) consisted of aortic-related death, including operative death, or aortic root–related reoperation as described by hazard ratio (HR) with 95% confidence interval (CI). Patients who died of distal aortic events were excluded from the aortic-related death figure. Eight variables for the multivariable regression model included age, male sex, total arch replacement, at least moderate preoperative AR, GRF glue use (compared with no glue use or fibrin glue use), entry tear at the aortic root or the sinotubular junction, preoperative Valsalva sinus diameter, and number of commissural detachments, which we considered clinically significant risk factors for adverse outcomes. Patient survival in our cohort was compared with that of the age-matched, sex-matched population by means of the Japanese population life table available from the Japanese Ministry of Health, Labor, and Welfare data.[17] Valsalva sinus diameter and AR, measured repeatedly with time in each participating subject, were analyzed with the linear mixed model with random intercepts and random slope. For these outcomes, the linear mixed models including the interaction term between time and each



VIDEO 1. Surgical procedure for supracoronary aortic replacement. After establishing cardiopulmonary bypass with arterial cannulation through the ascending aorta and bicaval venous drainage, total arch replacement with supracoronary aortic replacement was performed under moderate hypothermia. The feasibility of aortic crossclamping was confirmed with epiaortic ultrasonography, although the proximal ascending aortic false lumen was thrombosed. The proximal anastomosis was performed first, followed by the distal anastomosis. The aorta was transected 1 cm distal to the sinotubular junction. Proximal reapproximation was performed using polytetrafluoroethylene felt outside the adventitia, BioGlue (CryoLife Inc, Kennesaw, Ga) inside the false lumen, and a 4-0 polypropylene running suture. Commissural resuspension was performed with pledgeted sutures. After completion of the distal anastomosis, lower-body circulation was reinstituted, the patient was warmed, and the graft was anastomosed to the proximal aortic stump. Blood flow to the heart was then restored. The left subclavian, left common carotid, and innominate arteries were reconstructed sequentially. Video available at: https://www.jtcvs.org/article/S0022-5223(19)32365-7/fulltext.

baseline variable ie, preoperative Valsalva sinus diameter, preoperative AR, GFR glue use, number of commissural detachments, and graft size, were also analyzed.

Most of the data analyses was performed with JMP 11.0 software (SAS Institute Inc, Cary, NC). The cumulative incidence estimation was executed in EZR which is a graphical user interface for R (version 3.1.2; The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Patient Characteristics

Patient characteristics are summarized in Table 1. Mean age was 68.5 ± 12.3 years. Coronary malperfusion was observed in 16 patients (4.7%). Preoperative shock status (blood pressure <90 mm Hg) was found in 79 patients (23%), including 28 patients with cardiac arrest (8.3%). Preoperative AR grade was none or trivial in 187 patients (55%), mild in 80 patients (24%), moderate in 34 patients (10%), severe in 2 patients (0.6%), and unknown in 36 patients (11%). Preoperative Valsalva sinus diameter was 40.4 ± 5.2 mm, and sinotubular junction diameter was 37.0 ± 5.5 mm.

TABLE 1. Patient characteristics (n = 339)

Variable	Value
Age (y)	
Mean ± SD	68.5 ± 12.3
<60	71 (21)
60-69	91 (27)
≧70	177 (52)
Male sex	156 (46)
BSA (m^2)	1.63 ± 0.22
Organ malperfusion	103 (30)
Coronary malperfusion	16 (4.7)
Shock status (<90 mm Hg)	79 (23)
Cardiac arrest	28 (8.3)
AR grade	
None/trace	187 (55)
Mild	80 (24)
Moderate	34 (10)
Severe	2 (0.6)
Unknown	36 (11)
Duration from onset to operation (h)	6.5 (4.5-12.0)
DeBakey II	64 (19)
Thrombosed false lumen	64 (19)
Primary entry location	
Aortic root/STJ	7 (2.1)
Ascending	132 (39)
Aortic arch	115 (34)
Distal arch	53 (16)
Unknown	32 (9.4)
Valsalva sinus diameter (mm)	40.4 ± 5.2
STJ diameter (mm)	37.0 ± 5.5

Data are number and percentage of patients, mean ± SD, or median and interquartile range. *BSA*, Body surface area; *AR*, aortic regurgitation; *STJ*, sinotubular junction.

Early Outcomes

Operative data are shown in Table 2. There were no detached commissures in 204 patients (60%), 1 detached commissure in 100 patients (30%), 2 detached commissures in 28 patients (8.3%), and 3 detached commissures in 7 patients (2.1%). Mean cardiopulmonary bypass time was 197.6 ± 72.9 minutes. Total arch replacement was performed in 140 patients (41%). GRF glue was used in 153 patients (45%). Operative death occurred in 46 cases (13.7%). AR grade at discharge was none or trace in 279 patients (82.3%), mild in 56 patients (16.5%), and moderate in 4 patients (1.2%). Valsalva sinus diameter at discharge was 40.1 ± 4.5 mm.

Survival

During the observation period, 60 late deaths occurred, including 7 aortic-related deaths. In terms of aortic-related deaths, 3 patients refused additional aortic surgery and died of rupture secondary to residual dissection aneurysm at the downstream aorta. One patient died of graft infection after descending aortic replacement. The other patients died secondary to operation for residual

TABLE 2. Operative data (n = 339)

Variable	Value
Dissection involving Valsalva sinus	295 (87)
No. of detached commissures	
0	204 (60)
1	100 (30)
2	28 (8.3)
3	7 (2.1)
CPB time (min)	197.6 ± 72.9
Cardiac ischemic time (min)	105.5 ± 35.8
ACP	263 (77.6)
ACP time (min)	89.6 ± 59.1
Minimum tympanic temperature (°C)	20.2 ± 2.0
Minimum rectal temperature (°C)	25.4 ± 2.4
Circulatory arrest of lower body (min)	46.0 ± 17.9
Graft size (mm)	
22	31 (9.1)
24	156 (47)
26	137 (40)
28	13 (3.8)
Total arch replacement	140 (41)
Glue use	
GRF glue	153 (45)
BioGlue*	172 (51)
None	14 (4.1)
Operative mortality	46 (14)
Permanent neurologic deficit	59 (22)
Acute renal failure	22 (6.5)
Tracheostomy	23 (6.8)
Deep sternal wound infection	10 (2.9)

Data are number and percentage of patients or mean ± SD. *CPB*, Cardiopulmonary bypass; *ACP*, antegrade cerebral perfusion; *GRF*, gelatin-resorcinol-formaldehyde. *BioGlue; CryoLife Inc, Kennesaw, Ga.

dilation of the downstream aorta. One patient who had severe AR and refused aortic valve operation died of cardiac failure.

The 5-year and 10-year survivals were 73.9% ± 2.6% and 60.7% ± 3.6%, respectively. Overall survival was acceptable when compared with age- and sex-matched Japanese populations (89.8% at 5 years and 76.4% at 10 years; Figure 3, *A*). The cumulative incidences for aortic-related death were 14.5% at 5 years and 15.9% at 10 years (Figure 3, *B*). The cumulative incidences for non–aortic related death were 12.4% at 5 years and 21.4% at 10 years.

Aortic Root–Related Events

Twenty-five patients required a total of 25 operations for aortic root–related causes. The details of aortic root–related reoperation are summarized in Tables 2 and 3. Thirteen patients (4.5%) required reoperation for recurrent dissection at the aortic root, and 1 of these 13 patients underwent

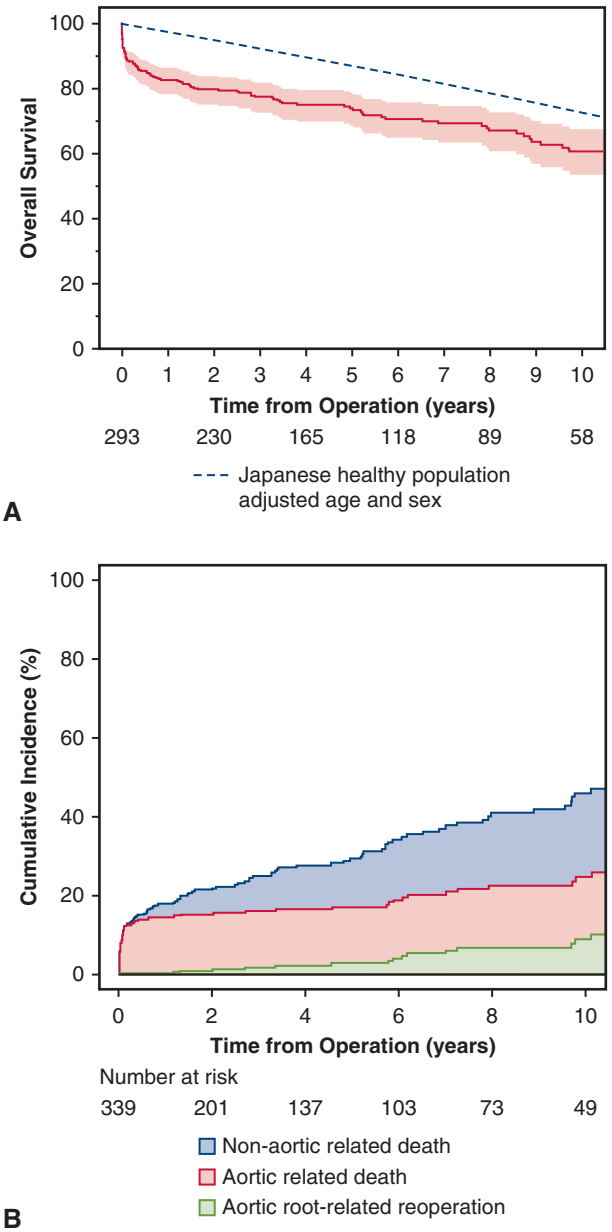


FIGURE 3. A, Overall survival versus age- and sex-matched Japanese healthy population. B, The cumulative incidences for aortic root–related reoperation (*green*; 2.6% at 5 years and 8.8% at 10 years), aortic-related death (*red*; 14.5% at 5 years and 15.9% at 10 years), and non–aortic related death (*blue*; 12.4% at 5 years and 21.4% at 10 years).

reoperation for persistence of the initial dissection. Three patients (1.0%) underwent reoperation for aortic root dilation. In sum, 6 patients (2.1%) received aortic valve replacements, 8 patients (2.8%) underwent the Bentall operation, and 11 patients (3.8%) underwent VSRR. The cumulative incidences for aortic root–related reoperation were 2.6% at 5 years and 8.8% at 10 years (Figure 3, *B*).

Stratified by the number of commissural detachments, the cumulative incidence for aortic root-related reoperation

TABLE 3. The details of aortic root–related reoperation

Variable	Value
Overall	25 (8.5)
Cause	
Recurrent dissection	13 (4.4)
False aneurysm	6 (2.0)
Aortic root dilation	3 (1.0)
Infective endocarditis	2 (0.7)
Degenerative AR	1 (0.3)
All procedures	
AVR	6 (2.0)
AVR with partial remodeling	4 (1.4)
Bentall operation	8 (2.7)
VSRR	11 (3.8)
Reimplantation	10 (3.4)
Partial remodeling	1 (0.3)

Data are number and percentage of patients. *AR*, Aortic regurgitation; *AVR*, aortic valve replacement; *VSRR*, valve-sparing root replacement.

was significantly higher according to the number (for 0, 0.9% at 5 years; for 1, 6.6% at 5 years; for 2 or 3, 18.6% at 5 years; $P = .023$). When stratified by the preoperative Valsalva sinus diameter greater than 45 mm, the cumulative incidence for aortic root-related reoperation was significantly higher in patients with Valsalva sinus diameter greater than 45 mm (<45 mm, 1.6% at 5 years; >45 mm, 16.3% at 5 years; $P = .002$).

Multivariable Cox hazard regression analysis demonstrated that a larger preoperative Valsalva sinus diameter (HR, 1.23 for increment of 1 mm; 95% CI, 1.10-1.37; $P < .001$) and an increased number of commissural detachments (HR, 2.06 for each commissural detachment; 95% CI, 1.24-3.27; $P = .007$) were significant risk factors for a composite outcome that consisted of aortic root–related reoperation and aortic-related death (Table 4).

In addition to the patients who underwent reoperation or died an aortic-related death, 17 patients had development of at least moderate AR in 4.8 years (2.7-7.0 years) after initial repair, and 27 patients had development of an aortic root diameter greater than 50 mm in 2.0 years (1.0-4.0 years). Excluding 11 patients who died of non–aortic related causes, 4 patients refused additional surgical repair and 29 patients were scheduled for surgical repair with close follow-up.

TABLE 4. Multivariable analysis for aortic root or valve–related reoperation

Variables	HR (95% CI)	*P* value
Age (1-y increment)	1.00 (0.96-1.04)	.893
Male sex	0.90 (0.33-2.41)	.833
Total arch replacement	0.75 (0.28-1.94)	.565
Moderate or greater AR	0.88 (0.19-2.90)	.843
GRF glue use	1.95 (0.77-5.62)	.164
Entry tear at aortic root/STJ	2.35 (0.12-12.9)	.474
Valsalva sinus diameter (1-mm increment)	1.23 (1.10-1.37)	<.001*
Commissural detachment (each)	2.06 (1.24-3.27)	.007*

HR, Hazard ratio; *CI*, confidence interval; *AR*, aortic regurgitation; *GRF*, gelatin-resorcinol-formaldehyde; *STJ*, sinotubular junction. *$P < .05$.

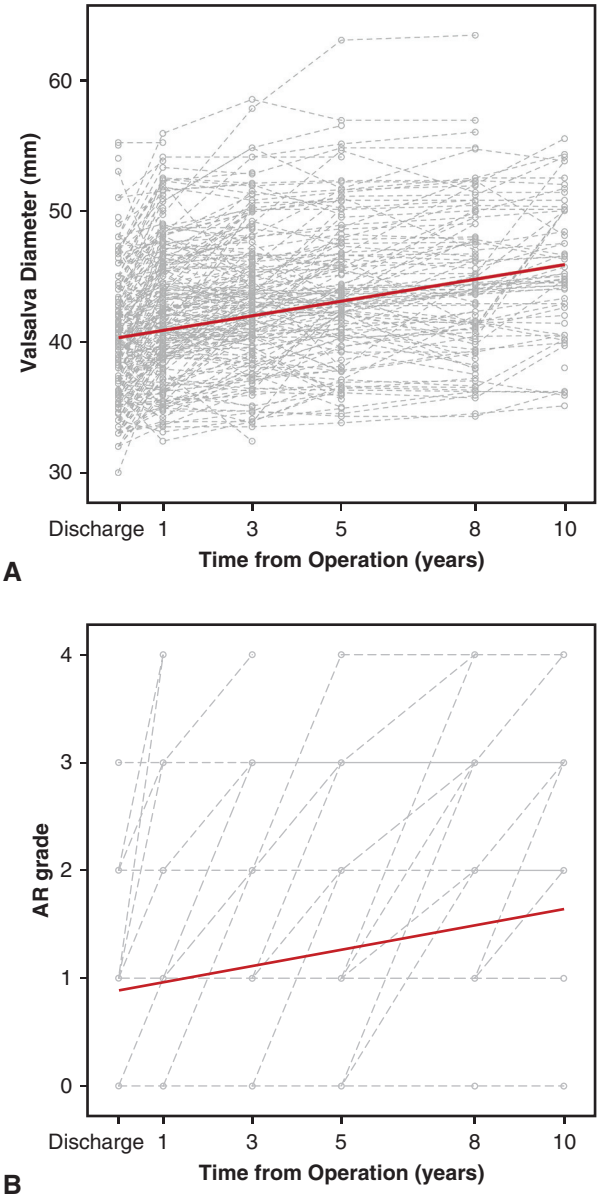


FIGURE 4. Time dependent changes in Valsalva sinus diameter (A) and aortic regurgitation (B).

Time-Dependent Changes

Valsalva sinus diameter. When the linear mixed model was used, Valsalva sinus diameter with time was estimated as 40.2 + (0.65 per year) mm, with the SDs for random

TABLE 5. Interaction between time and baseline variables for Valsalva sinus diameter and aortic regurgitation grade

Variables	Fixed effect	Estimate	*P* value
Valsalva sinus diameter			
Preoperative Valsalva sinus diameter (25.2-52.9 mm)	Intercept	19.4	
	Time	−0.26	
	Preoperative Valsalva sinus diameter	0.52	
	Interaction (preoperative Valsalva sinus diameter*time)	0.02	.016
No. of commissural detachments (0-3)	Intercept	39.7	
	Time	0.61	
	Number of commissural detachments	0.94	
	Interaction (no. of commissural detachments*time)	0.09	.094
GRF glue use (0 vs 1)	Intercept	40.4	
	Time	0.69	
	GRF glue use	−0.45	
	Interaction (GRF glue use*time)	−0.06	.416
Graft diameter (20-28 mm)	Intercept	25.1	
	Time	−0.32	
	Graft diameter	0.61	
	Interaction (graft diameter*time)	0.04	.17
Preoperative AR grade (0 to 4)	Intercept	39.8	
	Time	0.58	
	Preoperative AR grade	0.33	
	Interaction (preoperative AR grade*time)	0.06	.118
AR grade			
Preoperative Valsalva sinus diameter (25.2-52.9 mm)	Intercept	1.05	
	Time	−0.05	
	Preoperative Valsalva sinus diameter	−0.004	
	Interaction (preoperative Valsalva sinus diameter*time)	0.003	.161
No. of commissural detachment (0-3)	Intercept	0.84	
	Time	0.06	
	No. of commissural detachments	0.06	
	Interaction (no. of commissural detachments*time)	0.02	.028
GRF glue use (0 vs 1)	Intercept	1.01	
	Time	0.03	
	GRF glue use	−0.28	
	Interaction (GRF glue use*time)	0.08	<.001
Graft diameter (20-28 mm)	Intercept	−0.61	
	Time	−0.20	
	Graft diameter	0.06	
	Interaction (graft diameter*time)	0.01	.049
Preoperative AR grade (0-4)	Intercept	0.7	
	Time	0.06	
	Preoperative AR grade	0.16	
	Interaction (preoperative AR grade*time)	0.01	.183

GRF, Gelatin-resorcinol-formaldehyde; *AR*, aortic regurgitation.

intercept of 4.14, for random slope of 0.35, and for correlation coefficient of 0.17. There was a significant increase of Valsalva sinus diameter with time ($P < .001$; Figure 4, *A*).

The interactions between time and each variable are summarized in Table 5. There were significant interactions between greater preoperative Valsalva sinus diameter with time-dependent growth of Valsalva sinus diameter ($P = .016$). The number of commissural detachments ($P = .094$) showed a trend toward interaction with increasing postoperative Valsalva sinus diameter with time, although this did not reach statistical significance. No significant interactions were observed between time and GRF glue use ($P = .416$), graft diameter ($P = .170$), and preoperative AR grade ($P = .118$).

Aortic regurgitation. When the linear mixed model was used, AR grade with time was estimated as 0.9 + (0.07 per year) mm, with the SDs for random intercept of 0.7, for random slope of 0.01, and for correlation coefficient of −0.13. There was significant progression of AR with time ($P < .001$; Figure 4, *B*).

There were significant interactions between increasing number of commissural detachments ($P = .028$), GRF glue use ($P < .001$), and larger graft size ($P = .049$) with time-dependent progression of AR. No significant interactions were observed, however, between preoperative AR grade ($P = .183$) and preoperative Valsalva sinus diameter ($P = .161$) with progression of AR over time.

DISCUSSION

The findings of this study are summarized with the following 4 points (Figure 5). First, late durability of aortic valve competence after SCR was suboptimal, particularly 5 years after initial repair. Second, the major cause of reoperation was the progression of AR as a result of recurrent dissection. Third, commissural detachment and greater Valsalva sinus diameter were independent risk factors for unfavorable aortic root–related events. Finally, commissural detachment, GRF glue use, and larger graft size were risk factors for late AR progression.

The optimal strategy of proximal repair for patients with AAAD remains controversial. A recent registry report stated that the 30-day mortality remains between 10% to 17%.[18,19] With the improvement of surgical outcomes, several authors have demonstrated that ARR is not a risk factor for operative mortality in select patients.[20-22]

For open repair of AAAD, the extent of aortic repair should take into account the proximal and distal extents of lesions. Selection of the optimal strategy must be individually tailored, however, and must include careful consideration of patient factors. The strategy should balance the objective of maximizing the durability of repair to achieve the best long-term outcomes, which means performing a more aggressive or extensive operation to address all aortic segments that are pathologic or likely to deteriorate with time, while also acknowledging the patient's physiologic condition at the time of presentation. This means that sicker patients or those in unstable condition may require a more limited salvage operation that they are more likely to survive. Our previous study demonstrated that total arch replacement with elephant trunk insertion prevented unfavorable aortic growth in the downstream aorta relative to nontotal arch replacement.[14] In this study, SCR and ARR were not compared directly, because meticulous patient selection was inherent in our strategy, resulting in bias. We

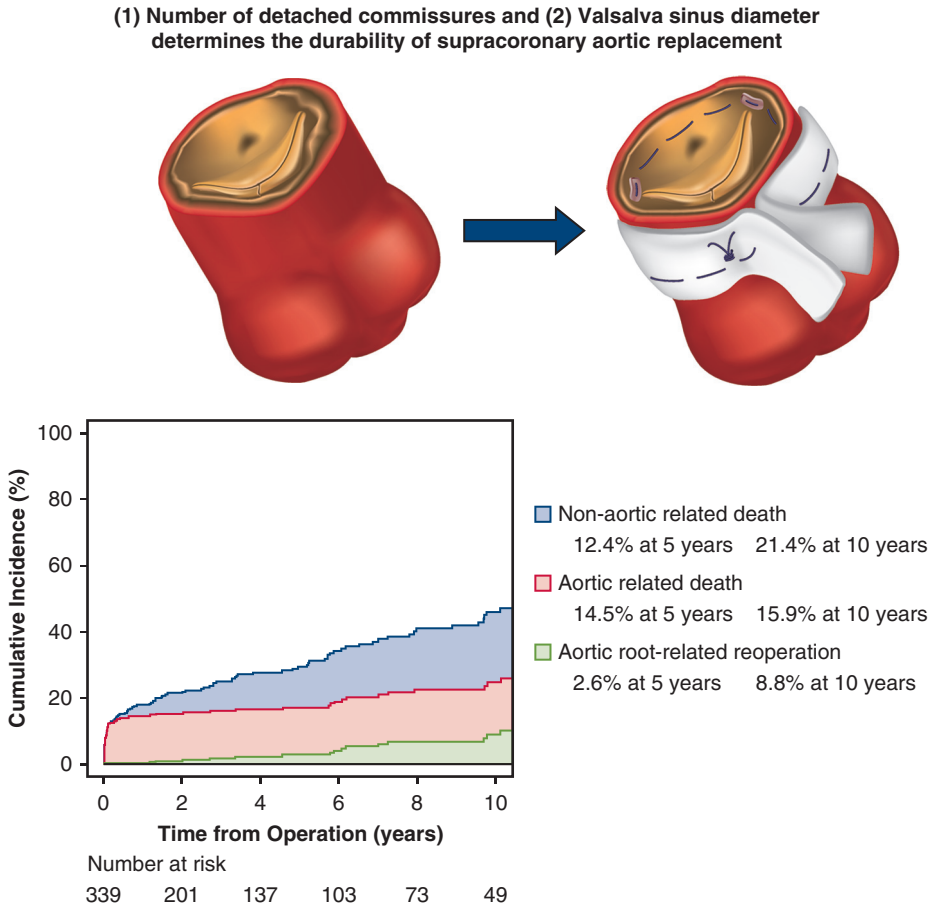
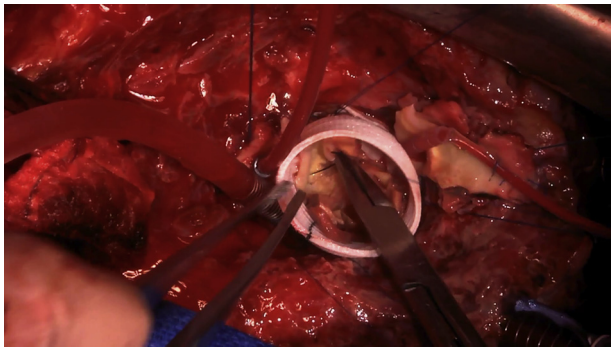


FIGURE 5. Summary of the results.



VIDEO 2. Valve-sparing root replacement for pseudoaneurysm. The patient initially underwent hemiarch replacement with supracoronary aortic replacement. There was detachment of 1 commissure (right and noncoronary commissures) at the initial surgery. The patient required reoperation for pseudoaneurysm, which developed 3 years after the primary repair. The cardiopulmonary bypass was established through femoral cannulation, and cooling was started before sternotomy. The pseudoaneurysm was observed at the proximal anastomosis with massive hemorrhage. The cross-clamp was performed by clamping the previous graft, and antegrade cardioplegia was injected, followed by retrograde cardioplegia. Residual dissection was found in the right and noncoronary commissures. The false lumen was filled with thrombus. The aortic root was replaced with a 24-mm Valsalva graft (Terumo Medical, Somerset, NJ) and secured with 12 reinforced 3-0 polyester mattress sutures in the first row and continuous 5-0 polypropylene sutures in the second row. Implantation of the coronary arteries and distal anastomosis were completed after confirmation of competency of the aortic valve. Video available at: https://www.jtcvs.org/article/S0022-5223(19)32365-7/fulltext.

believe, however, that our findings regarding late outcomes of SCR may provide new insights into improved decision making. Patients with a Valsalva sinus diameter greater than 45 mm or with more than 1 commissural detachment may be candidates for ARR, so long as these patients are in stable condition.

Recent literature has reported the incidences of late proximal reoperation after SCR to be 3.0% to 9.0% at 5 years and 8.0% to 23.2% at 10 years,[7,22-24] which is comparable to our outcomes (2.6% at 5 years and 8.8% at 10 years). Castrovinci and colleagues[7] demonstrated in a propensity-matched analysis that ARR might be protective against proximal aortic reintervention (at 7 years, ARR, 2.0% vs SCR, 14.0%; $P = .06$).

Three major indications have been suggested as the impetus for reoperation in SCR with preserved aortic root: (1) Valsalva sinus dilation, (2) pseudoaneurysm, and (3) recurrent dissection[25] (Video 2). It has been reported that SCR itself induces significant hemodynamic changes at the level of the aortic root by increasing parietal tension as a result of the rigidity of the adjacent vascular prosthesis.[26] The mean growth rate of the aortic root after SCR was 0.6 mm/y[25] We noted a similar growth rate in our study (0.65 mm/y), as estimated by the mixed-effects model with 10 years of follow-up data. The growth rate correlated with the initial diameter of the aortic root, such that larger baseline diameters demonstrated higher growth rates.[8] Our results found that Valsalva sinus diameter was a significant risk factor for unfavorable aortic root events, supporting these findings. Furthermore, aortic root expansion exacerbated AR as a result of reduced leaflet coaptation. Sinotubular junction plication with a smaller graft may be effective in preventing AR progression to some extent, although ARR would be preferable for patients presenting with large aortic roots. Proximal stepwise technique,[27] which incorporates another, smaller graft for the proximal anastomosis, may further improve long-term outcomes.

The extent of tissue fragility in the dissected aorta is thought to be a cause of pseudoaneurysm formation and recurrent dissection, as is glue necrosis caused by GRF glue use.[28] Rylski and associates[25] reported that dissection involvement of all 3 aortic sinuses is a significant risk factor for reoperation. We demonstrated that an increased number of commissural detachments resulted in unfavorable aortic root events. Root redissection, which was a dominant cause for reoperation in our study, was particularly associated with commissural detachment. In this setting, we consider the durability of SCR to be acceptable in patients with smaller Valsalva sinus diameters and without commissural detachment. When SCR is performed in patients with large Valsalva sinus diameters or commissural detachment because of unstable preoperative condition, we recognize that SCR is an acceptable lifesaving treatment for AAAD, even though root replacement may be preferred from a long-term outcome standpoint.

On the basis of the causes of reoperation mentioned previously, ARR was considered advantageous relative SCR for the prevention of (1) aortic root expansion, (2) pseudoaneurysm formation, and (3) recurrent dissection. Our previous study demonstrated that commissural detachment and GRF glue necrosis were also the causes of reoperation after VSRR for AAAD.[9] The Bentall operation thus may be favorable in patients with commissural detachment. Use of an appropriate biologic glue could resolve the issue of necrosis in VSRR. In the setting of intact aortic cusps, VSRR may be superior to the Bentall procedure, because tissue valves are accompanied by the risk for valve deterioration and mechanical valves require lifelong anticoagulation.

To assess the appropriateness of SCR, risk of reoperation should be considered. In this study, there were no operative deaths among the 25 patients undergoing reoperation 5.3 ± 3.4 years after the initial operation, despite the fact that 19 of these 25 patients underwent redo aortic root surgery, including 10 patients with VSRR. All reoperations were performed electively, and reoperation was not a risk factor for late death (HR, 0.52; 95% CI, 0.18-1.18; $P = .126$).

Late AR progression after AAAD repair was a nonnegligible complication requiring reintervention, in addition to distal reintervention. In our cohort, 38 patients required

additional surgery for distal dilation 4.7 ± 3.4 years after the initial operation, including 13 patients who underwent aortic surgery through a thoracotomy. Five of 13 patients required surgical correction of moderate to severe AR before descending or thoracoabdominal aortic repair with circulatory arrest. AR progression should be taken into account as a part of total aortic care after the initial surgical repair for AAAD. We did not encounter patients with aortic root rupture in this study, although 3 patients required reoperation for an aortic root diameter greater than 55 mm and 27 patients required reoperation of roots larger than 50 mm. Given that there were no cases of aortic root rupture despite late root dilation, further study is required to determine the optimal surgical indications for aortic root reintervention after AAAD repair.

Limitations

There are several limitations of our study. First, this was a retrospective study from a single center. Second, our surgical technique has evolved slightly during the observation period; however, we included all patients in the study because earlier patients provided additional long-term results. Although the follow-up rate was acceptable (96.9%), there were a small number of patients at risk at later time points because of life-threatening background. Third, complete CT follow-up data were only available for 61 of 339 patients, and analysis was performed by a single analyst. Finally, events such as aortic root–related reoperation may include medical decision bias.

CONCLUSIONS

Valsalva sinus diameter and commissural detachment were independent predictors for unfavorable aortic root outcomes. GRF glue use and larger graft size might be risk factors for late AR progression. Although late outcomes of SCR were primarily acceptable in patients without these risk factors, we should recognize SCR as an acceptable life-saving treatment for AAAD in patients with root involvement who are in unstable condition. Particularly for these patients, close follow-up with CT and echocardiography is necessary, and ARR at the time of initial operation may lead to more favorable late outcomes if patients can tolerate the more extensive procedure.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: aortic arch, aortic operation, aortic dissection

TABLE E1. Characteristics of patients undergoing root replacement (n = 27)

Variable	Value
Age (y)	58.4 ± 11.3
Male sex	25 (93)
BSA (m^2)	1.75 ± 0.17
Organ malperfusion	6 (22)
Coronary malperfusion	0 (0)
Shock status (<90 mm Hg)	8 (30)
Cardiac arrest	4 (15)
AR grade	
None/trace	3 (11)
Mild	9 (33)
Moderate	8 (30)
Severe	5 (19)
Unknown	2 (7.4)
Duration from onset to operation (h)	6.0 (3.5-15.0)
DeBakey II	7 (26)
Thrombosed false lumen	4 (15)
Primary entry location	
Aortic root/STJ	9 (33)
Ascending	13 (48)
Aortic arch	3 (11)
Distal arch	0 (0)
Unknown	2 (7.4)
Valsalva sinus diameter (mm)	54.3 ± 12.2
STJ diameter (mm)	46.2 ± 9.4

Data are number and percentage of patients, mean ± SD, or median and interquartile range. *BSA*, Body surface area; *AR*, aortic regurgitation; *STJ*, sinotubular junction.

TABLE E2. Operative data and early outcomes of patients undergoing root replacement (n = 27)

Variable	Value
Dissection involving Valsalva sinus	22 (81)
No. of detached commissures	
0	10 (38)
1	8 (31)
2	7 (27)
3	2 (7.4)
CPB time (min)	305.4 ± 65.7
Cardiac ischemic time (min)	202.3 ± 35.7
ACP	23 (85)
ACP time (min)	93.8 ± 64.5
Minimum tympanic temp. (°C)	22.4 ± 3.3
Minimum rectal temp. (°C)	25.8 ± 2.9
Circulatory arrest of lower body (min)	37.2 ± 17.9
Graft size (mm)	
22	0 (0)
24	2 (7.4)
26	12 (44)
28	12 (44)
30	1 (3.7)
Total arch replacement	11 (41)
Valve-sparing reimplantation	18 (67)
Glue use	
GRF glue	9 (33)
BioGlue*	6 (22)
None	12 (44)
Operative mortality	6 (22)
Permanent neurologic deficit	2 (7.4)
Acute renal failure	3 (11)
Tracheostomy	1 (3.7)
Deep sternal wound infection	0 (0)

Data are number and percentage of patients or mean ± SD. *CPB*, Cardiopulmonary bypass; *ACP*, antegrade cerebral perfusion; *GRF*, gelatin-resorcinol-formaldehyde. *BioGlue; CryoLife Inc, Kennesaw, Ga.