The long-term fate of ascending aorta aneurysm after wrapping versus replacement

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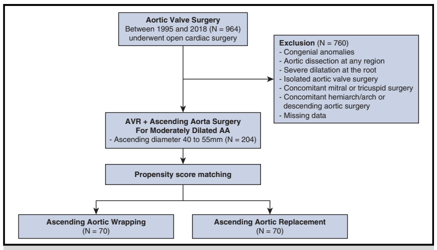
ABSTRACT

Objective: The study objective was to examine the long-term fate of aortic diameter expansion at 4 cardiac regions (annulus, sinus, ascending aorta, and proximal arch) after wrapping or replacement during aortic valve surgery of the moderately dilated ascending aorta.

Methods: From January 1995 to December 2018, 964 consecutive patients who underwent aortic valve replacement at our institution were reviewed. Of them, 204 (mean age, 60.7 $\pm$ 7.4 years) underwent ascending aorta wrapping (n = 96) or replacement (n = 108) for a moderately dilated ascending aorta (40 to 55 mm). The overall fate of the aortic diameter was analyzed with a linear mixed-effect model. The median follow-up duration was 7.1 years.

Results: After propensity score matching, the baseline maximal ascending aortic diameter median value was 47.3 $\pm$ 3.1 mm and 49.4 $\pm$ 13.5 mm in the wrapping and replacement groups, respectively. The annulus, sinus, and ascending aorta did not redilate in either group. The proximal aortic arch diameter significantly increased over time (0.343 mm/year; P = .006) in the wrapping group but not in the replacement group (0.066 mm/year; P = .649). Multivariable competing risk analysis identified the initial ascending aorta diameter at the wrapping procedure as an independent risk factor of proximal arch redilation (0.071 $\pm$ 0.037, P < .001). The cutoff value was an initial ascending aorta diameter of 47.2 mm for the prediction proximal arch redilation (area under the curve, 0.703; P = .014).

Conclusions: Aortic wrapping and replacement may be long-term durable treatment options in patients with a moderately enlarged ascending aorta. We suggest careful evaluation of redilation in the proximal arch after an aorta wrapping procedure. (J Thorac Cardiovasc Surg 2022;164:463-74)



Summary flow diagram of the study population. With a PS-matching analysis, patients were matched in a 1:1 ratio with 70 patients in each surgical group. *AVR*, Aortic valve replacement; *AA*, ascending aorta.

CENTRAL MESSAGE

AAW and AAR are long-term treatment options for patients with a moderately enlarged ascending aorta. Proximal arch redilation after the wrapping procedure requires monitoring.

PERSPECTIVE

Although ascending AAW in a moderately dilated ascending aorta shows acceptable long-term outcomes, there is a higher risk of redilation at the proximal arch than after AAR. Therefore, in patients with an initial mid-ascending aortic diameter more than 47 mm, surveillance methods such as careful echocardiography or CT evaluations may be warranted.

See Commentaries on pages 475, 476, and 478.

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A significant proportion of patients who undergo aortic valve replacement (AVR) are reported to have a dilated ascending aorta.[1] Several observational studies have shown that an untreated ascending aorta aneurysm may predispose the patient to fatal aortic dissection or rupture.[2,3]

Advances in surgical techniques and the development of new materials have made it possible to completely remove and replace the affected aorta with biological conduits.[4] Results from recent studies revealed that early mortality for elective replacement of the ascending aorta was

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Number of Institutional Review Board approval: 4-2018-0740; date approved: April 2018.

Accepted for the 100th Annual Meeting of The American Association for Thoracic Surgery.

Received for publication May 29, 2020; revisions received Dec 15, 2020; accepted for publication Dec 16, 2020; available ahead of print Jan 19, 2021.

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0022-5223

https://doi.org/10.1016/j.jtcvs.2020.12.110

Abbreviations and Acronyms

- AAR = ascending aortic replacement
- AAW = ascending aortic wrapping
- AVR = aortic valve replacement
- BSA = body surface area
- CT = computed tomography
- LMM = linear mixed-effects model
- PS = propensity score
- PTFE = polytetrafluoroethylene

Scanning this QR code will take you to the table of contents to access supplementary information.

3.4%.[5] However, this figure increased significantly when the procedure was performed in elderly patients with multiple comorbidities, which ranged from 4% to 20%.[6] In elderly patients, a conservative surgical approach for aneurysm may be beneficial, because it is simpler and involves a lower risk.

In these circumstances, a wrapping technique can be attempted to reduce the diameter of the aorta and to reinforce the wall and prevent subsequent dilatation.[4] However, the results of a nationwide survey in the United States regarding aortoplasty with and without wrapping found that it was considered a controversial procedure.[7,8] These reports have been mostly observational studies based on short-term data. Furthermore, only a few reports that have presented postoperative aortic redilation over time have indicated skepticism regarding these surgical techniques.[9-11]

Therefore, we sought to compare the long-term outcomes of patients according to the different methods used to manage the moderate dilated ascending aorta: ascending aortic wrapping (AAW) or ascending aortic replacement (AAR). We performed a linear mixed model analysis of the serial change in diameter of distinct levels of the ascending aorta.

MATERIALS AND METHODS

Ethics Statement

This study was approved by the Ethics Committee/Review Board of the Severance Hospital, Republic of Korea (Institutional Review Board Number: 4-2018-0740), and the committee waived the requirement for informed consent from the individual patient because of the retrospective nature of study.

Patient Selection

This single-center, retrospective, propensity score (PS)-matched study included 964 consecutive patients who underwent AVR with concomitant ascending aortic dilatation of 40 to 55 mm at our institution from January 1995 to December 2018. We excluded patients with defined congenital anomalies and aortic dissections, and patients who underwent isolated AVR or aortic valve repair instead of replacement, root surgical procedures, concomitant other valve (mitral or tricuspid) surgery, or hemiarch/arch and descending aorta replacement.

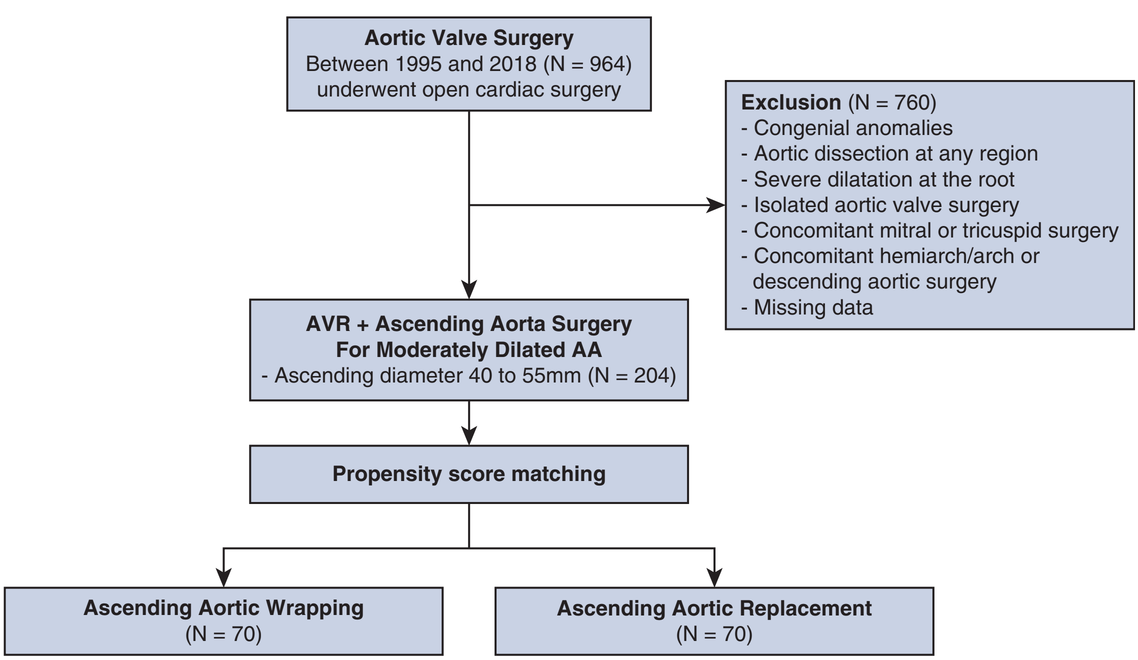


FIGURE 1. Summary flow diagram of the study population. With a PS-matching analysis, patients were matched in a 1:1 ratio with 70 patients in each surgical group. *AVR*, Aortic valve replacement; *AA*, ascending aorta.

Definition of Groups

A total of 204 patients (mean age, 60.7 ± 7.4 years) underwent AVR with the ascending aortic procedure. The patients were divided into 2 groups: the ascending aorta wrapping (AAW, n = 96) group and ascending aorta replacement (AAR, n = 108) group. The decision to perform concomitant aortic procedures was influenced by aortic size, morphology of the aortic valve, and expected surgical risks of complications affecting left ventricular function. The patient flowchart is shown in Figure 1.

Operative Techniques

Ascending aortic wrapping. AAW was performed after the completion of hemostasis and protamine reversal after AVR. Polytetrafluoroethylene (PTFE) or double-velour vascular grafts were used to surround the native ascending aorta (Figure 2, *A*). The vascular graft length was determined according to the distance between the ST junction and the origin of the innominate artery (Figure E1 and Video 1). The maximal diameter of commercially available tubular grafts is 38 mm. Therefore, this diameter is, theoretically, the maximal possible aortic diameter after

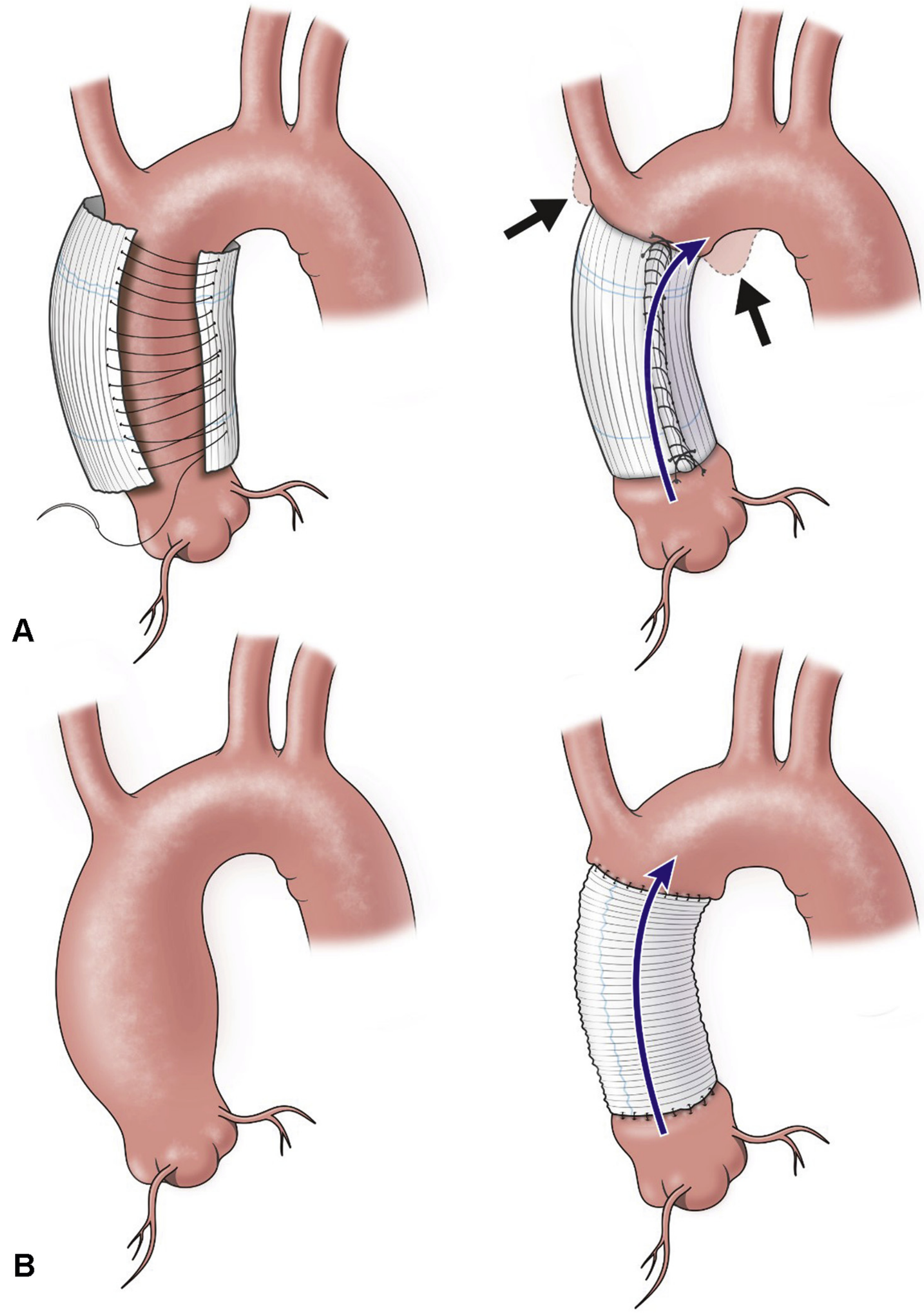
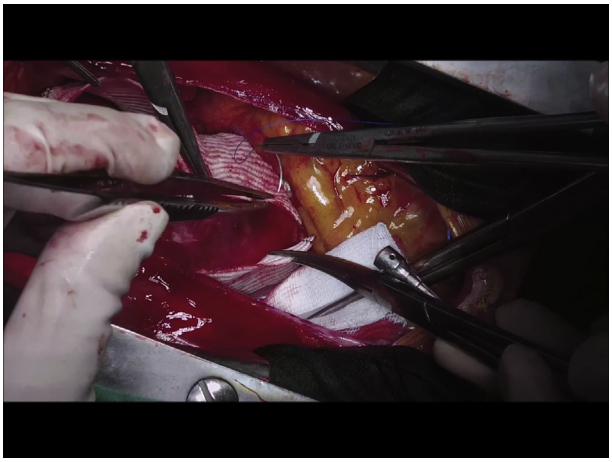


FIGURE 2. Ascending aortic procedure with (A) AAW and (B) AAR. *Blue arrow* represents the expected blood flow through the ascending aorta after surgery. *Black arrow* indicates that the proximal arch diameter significantly increased over time after surgery of AAW.



VIDEO 1. The AAW procedure in the operating room. Video available at: https://www.jtcvs.org/article/S0022-5223(21)00002-7/fulltext.

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wrapping. However, we usually used a 30-mm Hemashield graft (maximal 34 mm, if needed) for the wrapping procedure. We made a wrap by vertical incision of graft and wrapped it in the horizontal direction. Once the native aorta was surrounded by the graft, the graft was sewn to adventitia by continuous suturing with 4-0 or 3-0 polypropylene sutures (Prolene; Ethicon, Inc, Somerville, NJ). To prevent graft migration, several fixation stitches were made on the adventitia at the proximal and distal parts of the graft.[12] We set the target blood pressure to less than 90 mm Hg for the wrapping procedure to prevent an increase in systemic vascular resistance.

Ascending aortic replacement. For patients who underwent concomitant aorta replacement, commercially available vascular grafts were used for replacement of the aorta (Figure 2, *B*). For patients who required open distal aorta anastomosis, antegrade selective cerebral perfusion was used during circulatory arrest under moderate systemic hypothermia.

End Points and Definitions

The hypothesis to be elucidated through this study was "Is there a difference in long-term outcome between AAW and AAR in moderately dilated ascending aorta?" The primary end points were all-cause death, adverse aortic events, operative morbidities, including neurologic events (stroke and spinal cord ischemia), and pulmonary complications after AAW and AAR. Data were obtained through regular visits to the outpatient clinic. Early mortality was defined as death within 30 days of surgery.

The secondary end point was the diameter change of the aorta during follow-up. Serial postoperative echocardiographic and computed tomography (CT) images were reviewed to assess changes in maximal diameter at individual aortic levels in patients who underwent AVR with wrapping or replacement of the ascending aorta. Follow-up protocols included completion of clinical examinations and CT scans before discharge, 6 months postoperatively, and annually thereafter. Follow-up was completed in 95.6% (n = 195/204) of the whole cohort.

In this study, adverse aortic events were defined as the need for arch or descending aorta surgery, the occurrence of aortic dissection/rupture, or sudden death during the follow-up. Aortic redilation was defined as a stretched case compared with immediately after surgery and expressed as a positive continuous variable. The significant redilation of aorta was defined as increased by 20% or more compared with immediately after surgery.

Statistical Analysis

Categorical variables were summarized using frequencies and percentages and were compared by Fisher exact test or Pearson's chi-square analysis. Continuous variables were analyzed using the mean ± standard deviation with median and interquartile range, and were compared by independent *t* test or Mann–Whitney *U* test.

The resulting PS represented the probability of a patient undergoing AAW. Pairs of patients receiving AAR and AAW were derived using 1:1 matching with a caliper of width of 0.2 standard deviation of the logit of the PS. The quality of the match was assessed by comparing selected pretreatment variables in the PS-matched patient using the standardized mean difference, by which an absolute standardized difference greater than 10% is suggested to represent meaningful covariate imbalance. Analytic methods for the estimation of the treatment effect in the matched sample included McNemer's test to compare proportions.

Statistical analysis using a linear mixed-effects model (LMM) was performed to analyze the overall outcomes of aortic diameter for individual aortic procedures. The following variables were included in the univariable model: age, sex, body surface area (BSA), presence of bicuspid aortic valve or hypertension, wrapping material (PTFE or another material), and the initial ascending aortic diameter. Four variables were included in the multivariable model, with a significance level of .10. For the time and aortic adverse events, the analysis was conducted using a time-dependent Cox model in which AAW was a time-dependent covariate in the group variable, and annulus, sinus, ascending aorta, and proximal arch diameter were included. The cox.zph plot was used to estimate of time-dependent coefficients. The proportional hazards model estimated an average hazard over time, the value of which is shown in Figure E2.

To determine the best threshold for aortic diameter with redilation as a confounding factor, receiver operating characteristic curve analysis was performed. The Kaplan–Meier method was used to generate survival curves and calculate 5- and 10-year survival statistics and freedom from significant redilation. The IBM SPSS Statistics package (version 23.0, IBM-SPSS Inc, Armonk, NY) was used for all statistical analyses.

RESULTS

Demographics and Intraoperative Data

Baseline demographic, clinical, and echocardiographic parameters are detailed in Table 1. Patients who underwent AVR with concomitant AAR were younger ($P = .037$), were biased toward the female sex ($P = .067$), were more likely to have a bicuspid valve ($P = .038$), and had more hypertension ($P < .001$), diabetes mellitus ($P < .01$), and coronary artery obstructive disease ($P = .018$) compared with those who underwent AAW. Aortic clamping and cardiopulmonary bypass times were significantly longer in patients who underwent AAR than in those who underwent AAW ($P = .025$, <.001, respectively). The mid-ascending aortic diameter according to BSA is shown in Figure E3.

Before matching, patients receiving AAR were significantly different from those receiving AAW; overall, 5 of 21 pretreatment covariates showed standardized mean difference greater than 10%. Overall, patients receiving AAW presented a higher-risk profile. PS matching created a total of 70 matching sets. After matching, all covariates were well balanced between the 2 groups, with standardized mean difference less than 10% for all pretreatment variables.

The mean preoperative mid-ascending aortic diameter was 47.3 mm in the AAW group versus 49.4 mm in the AAR group ($P = .170$). The median valve size was 21 mm (interquartile range, 18-25 mm). The maximum

TABLE 1. Baseline characteristics of patients

Characteristics	Before PS matching				After PS matching			
	AAW (n = 96)	AAR (n = 108)	*P* value	SMD	AAW (n = 70)	AAR (n = 70)	*P* value	SMD
Age, y	62.3 ± 8.5	58.9 ± 13.9	.037	12	61.7 ± 8.4	60.0 ± 13.9	.075	8
Sex (male)	59 (61.5)	52 (48.2)	.067	7	32 (45.7)	41 (58.6)	.175	6
BSA (m^2)	1.7 ± 0.2	1.7 ± 0.2	.651	3	1.7 ± 0.2	1.7 ± 0.2	.612	3
Aortic phenotype								
Bicuspid	54 (56.3)	70 (64.8)	.038	8	26 (37.1)	38 (54.3)	.066	9
Tricuspid	42 (43.8)	37 (34.3)			44 (62.9)	32 (45.7)		
Aortic valve disease								
AS	40 (41.7)	40 (37.0)	.998	1	32 (45.7)	27 (38.6)	.555	4
Aortic regurgitation	19 (19.8)	28 (25.9)	.523	4	10 (14.3)	19 (27.1)	.071	9
Mixed ASR	37 (38.5)	40 (37.0)	.844	2	28 (40.0)	24 (34.3)	.583	4
Marfan syndrome	2 (2.1)	3 (2.8)	.461	4	0	2 (2.9)	.633	3
Hypertension	39 (40.6)	77 (71.3)	<.001	78	29 (41.4)	40 (57.1)	.120	7
Diabetes mellitus	4 (4.2)	4 (3.7)	<.001	26	0	2 (2.9)	.633	3
Chronic renal failure	4 (4.2)	7 (6.5)	.340	5	2 (2.9)	5 (7.1)	.219	6
Cerebrovascular accidents history	6 (6.3)	2 (1.9)	.105	7	0	0	-	
Coronary artery disease	12 (12.5)	4 (3.7)	.018	14	5 (7.1)	1 (1.4)	.069	9
Chronic obstructive pulmonary disease	7 (7.3)	2 (1.9)	.060	9	2 (2.9)	0	.680	2
Peripheral arterial disease	2 (2.1)	1 (0.9)	.456	4	0	1 (1.4)	.999	1
Hyperlipidemia	9 (9.4)	4 (3.7)	.064	9	3 (4.3)	2 (2.9)	.914	1
NYHA functional class (III-IV)	40 (41.7)	45 (41.7)	.999	1	21 (30)	29 (41.4)	.588	4
Smoking	18 (18.8)	24 (22.2)	.331	5	16 (22.9)	11 (15.7)	.496	4
LVEF, %	63.5 ± 7.3	61.2 ± 13.9	.297	5	62.4 ± 12.2	62.0 ± 6.9	.242	5
Aortic annulus (mm)	21.8 ± 3.4	21.3 ± 4.0	.535	4	21.4 ± 3.3	21.2 ± 3.9	.794	2
Mid-ascending aorta (mm)	45.2 ± 3.2	49.5 ± 12.8	.023	13	47.3 ± 3.1	49.4 ± 13.5	.170	6
Prosthetic valve type								
Mechanical	55 (57.3)	78 (72.2)	.054		42 (60.0)	54 (77.1)	.051	
Biological	41 (42.7)	30 (27.8)			28 (40.0)	16 (22.9)		
Concomitant CABG	7 (7.3)	4 (3.7)	.420		3 (4.3)	2 (2.9)	.536	
Aortic crossclamp time (min)	83.0 ± 26.6	97.0 ± 38.9	.025		82.7 ± 28.1	98.7 ± 34.7	.011	
Cardiopulmonary bypass time (min)	115.4 ± 34.3	168.3 ± 62.8	<.001		119.6 ± 23.2	173.5 ± 71.7	<.001	
Total circulatory arrest time (min)	-	33.8 ± 17.0	-		-	34.2 ± 19.5	-	

Values are presented as mean ± standard deviation or n (%). *PS*, Propensity score; *AAW*, ascending aortic wrapping; *AAR*, ascending aortic replacement; *SMD*, standardized mean difference; *BSA*, body surface area; *AS*, aortic stenosis; *ASR*, aortic stenosis and regurgitation; *NYHA*, New York Heart Association; *LVEF*, left ventricular ejection fraction; *CABG*, coronary artery bypass graft surgery.

conduit size was 34 mm in the AAW group and 32 mm in the AAR group. Aortic clamping and cardiopulmonary bypass times were significantly longer in patients who underwent AAR than in those who underwent AAW.

Early Outcomes

Table 2 shows detailed postoperative outcomes for the AAW and AAR groups. There was no in-hospital mortality for either group. Two patients (2.1%) in the AAW group and 3 patients (2.8%) in the AAR group experienced low cardiac output syndrome; these patients were not included in the PS-matched groups. New-onset arrhythmia and required pacemaker insertion rates were similar for the 2 groups ($P = .289$, .999, respectively). Each group included 1 patient who underwent reoperation because of bleeding.

Compared with the AAR, the AAW technique significantly reduced the need for a tracheostomy, which was related to a lower incidence of perioperative complications. However, after PS matching, there was no difference in lung complications by group. The median length of intensive care unit stay and length of postoperative stay were longer in the AAR group than in the AAW group.

TABLE 2. Postoperative outcomes by group

Operative outcomes	Total (N = 204)	Before PS matching AAW (N = 96)	AAR (N = 108)	P value	After PS matching AAW (N = 70)	AAR (N = 70)	P value
In-hospital mortality	0	0	0	-	0	0	-
Overall mortality	23 (11.3)	11 (11.5)	12 (11.1)	.661	4 (5.7)	6 (8.6)	.727
Low cardiac output syndrome	5 (2.5)	2 (2.1)	3 (2.8)	.999	0	0	-
New-onset arrhythmia	16 (7.8)	8 (8.3)	8 (7.4)	.504	7 (10.0)	5 (7.1)	.289
Required pacemaker	6 (2.9)	2 (2.1)	4 (3.7)	.686	2 (2.9)	3 (4.3)	.999
Reoperation due to bleeding	5 (2.5)	2 (2.1)	3 (2.8)	.999	1 (1.4)	1 (1.4)	-
Acute kidney injury	7 (3.4)	3 (3.1)	4 (3.7)	.146	1 (1.4)	2 (2.9)	.999
New dialysis	2 (1.0)	1 (0.9)	1 (0.9)	.529	0	0	-
Lung complication	9 (4.4)	3 (2.8)	6 (5.6)	.146	2 (2.9)	4 (5.7)	.687
Tracheostomy	1 (0.5)	1 (0.9)	4 (3.7)	.023	1 (1.4)	3 (4.3)	.625
GI bleeding	1 (0.5)	1 (0.9)	0	.365	1 (1.4)	0	.999
Permanent stroke	8 (3.9)	4 (4.2)	4 (3.7)	.572	3 (4.3)	3 (4.3)	-
Wound infection	5 (2.5)	3 (3.1)	2 (1.9)	.556	2 (2.9)	2 (2.9)	-
ICU stay, d	3.8 ± 2.0	3.4 ± 2.9	4.8 ± 1.9	.103	2.7 ± 3.1	4.7 ± 1.7	.027
Hospital stay, d	16.7 ± 20.3	14.9 ± 25.5	18.3 ± 14.0	.233	11.6 ± 6.6	17.7 ± 14.2	.002

Values are presented as mean ± standard deviation or n (%). *PS*, Propensity score; *AAW*, ascending aortic wrapping; *AAR*, ascending aortic replacement; *GI*, gastrointestinal; *ICU*, intensive care unit.

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Progress of Aortic Diameter (Annulus, Sinus, Tubular Ascending Aorta, and Proximal Arch)

In time-effect comparison, Table 3 compares the maximal cross-sectional aortic diameter immediately after surgery and at follow-up. There were no differences at the annulus, sinus, or tubular ascending aorta noted between the AAW and AAR groups.

The individual tree of distinct aortic diameter was measured to evaluate the overall fate of the ascending aorta after surgery (Figure 3). LMM also indicated that the diameter at the other aortic levels did not change over time. However, the proximal aortic arch significantly increased over time (0.343 mm/year; $P = .006$) in the AAW group; there was no meaningful redilation (0.066 mm/year; $P = .649$) in the AAR group.

Predictors for Redilation of the Proximal Arch

The male sex, preoperative ascending aortic diameter, and presence of hypertension were the significant predictors associated with redilation of the aorta in statistical analysis using univariable LMM ($P = .003$, <.001, <.001, respectively) (Table 4). However, preoperative aortic valve disease or the use of PTFE wrapping material had no significant effects on the rate of aortic arch redilation ($P = .241$, .171, respectively). The multivariable LMM for the ascending aortic diameter indicated that the preoperative ascending aortic diameter (0.071 ± 0.037, $P < .001$) was the independent predictor for proximal aortic redilation. In the AAW (reference; aortic replacement = 0) and age-adjusted models using time-dependent Cox model, it might be that the change in diameter of proximal arch over time has a significant effect on the occurrence time of aortic adverse events (Table 5).

Late Outcomes

The maximum follow-up time was 21.7 years (median, 7.1 years) (interquartile range, 3.9-11.2 years). During follow-up periods, the overall mortality rates were 5.7%

TABLE 3. Comparison of maximal cross-sectional aortic diameter immediately after surgery with diameter at follow-up

Aorta region (mm)	AAW (N = 70) Baseline	Median	Last	P value	AAR (N = 70) Baseline	Median	Last	P value
Annulus	20.9 ± 4.2	21.6 ± 6.2	23.9 ± 4.8	.528	20.7 ± 3.2	20.8 ± 6.2	21.4 ± 2.9	.975
Sinuses of Valsalva	37.6 ± 6.8	37.7 ± 7.1	37.7 ± 5.7	.524	36.7 ± 5.6	37.1 ± 7.4	37.9 ± 4.8	.894
Ascending aorta	31.3 ± 6.0	31.9 ± 6.9	32.2 ± 6.8	.124	29.7 ± 5.4	29.0 ± 3.7	29.1 ± 5.3	.515
Proximal Aortic arch	36.6 ± 8.0	37.5 ± 8.2	38.9 ± 6.9	.006	33.2 ± 4.8	33.8 ± 6.9	34.3 ± 5.3	.649

Baseline was the immediate postoperative measurement. The median and final follow-up were conducted using CT or echocardiography measurements. *P* value was calculated by mixed-effect model. *AAW*, Ascending aortic wrapping; *AAR*, ascending aortic replacement.

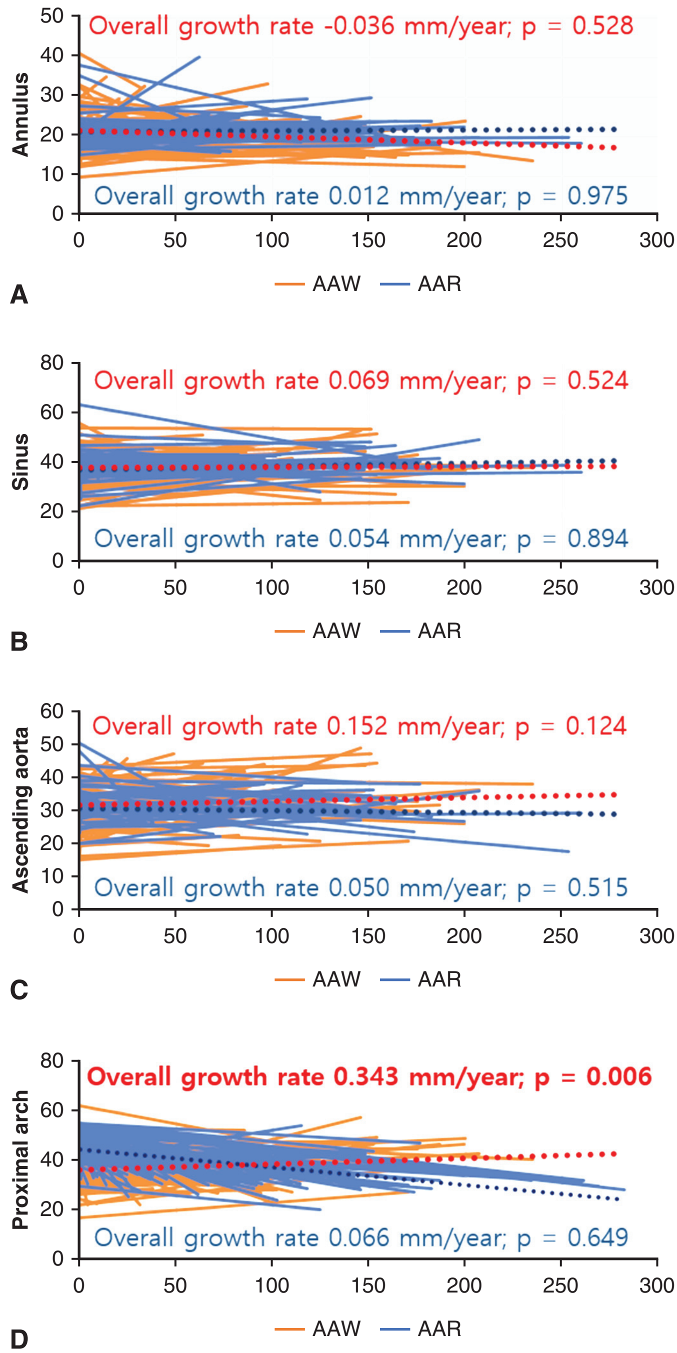

FIGURE 3. Comparison of changes in aortic diameter over time using spaghetti plot after AAW (*orange line*) and AAR (*blue line*). Aortic diameters were measured at the level of (A) annulus, (B) sinus, (C) ascending aorta, and (D) proximal arch. Trend lines indicate the overall dilation rate calculated using the univariable linear mixed model. *AAW*, Ascending aortic wrapping; *AAR*, aortic valve replacement.

and 8.6% in the AAW and AAR groups, respectively (P = .727). In unmatched and matched populations, the overall survival did not significantly differ between the AAW and AAR groups (Figure 4, *A* and *B*). However, in the matched comparison, the AAW group experienced a significantly higher incidence of aortic adverse events (24.3%, 17/70 patients) compared with the AAR group (14.3%, 10/70 patients) (P = .010, Figure 4, *D*). Significant redilation of the proximal arch was observed in 12 patients (17.1%) in the AAW group and 8 patients (11.4%) in the AAR group (P = .235). Among them, late reoperations for aortic dissection or rupture were performed for 8 patients (11.4%) in the AAW group and 4 patients (5.7%) in the AAR group (P = .366).

TABLE 4. Statistical analysis using linear mixed model for redilation of the proximal arch

	B ± standard error	*P* value
Univariable linear mixed model		
Age (y)	0.469 ± 0.296	.114
Sex (male)	−0.034 ± 0.011	.003
BSA (m^2)	0.170 ± 0.145	.241
Preoperative aortic diameter (mm)	0.083 ± 0.056	<.001
Bicuspid aortic valve	0.012 ± 0.013	.354
Aortic valve disease (AS vs AR vs mixed ASR)	0.027 ± 0.019	.241
Hypertension	0.039 ± 0.008	<.001
Chronic renal failure	0.033 ± 0.034	.327
Diabetes mellitus	0.013 ± 0.020	.514
Hyperlipidemia	0.047 ± 0.038	.217
Chronic obstructive pulmonary disease	0.029 ± 0.077	.709
Cerebrovascular accidents history	0.079 ± 0.084	.348
The use of PTFE material	−0.027 ± 0.018	.171
Multivariable linear mixed model		
Sex (male)	−0.029 ± 0.020	.091
Preoperative aortic diameter (mm)	0.071 ± 0.037	<.001
Hypertension	0.040 ± 0.020	.453

BSA, Body surface area; *AS*, aortic stenosis; *AR*, aortic regurgitation; *ASR*, aortic stenosis and regurgitation; *PTFE*, polytetrafluoroethylene.

The cutoff values for the preoperative ascending aorta diameter and BSA-indexed ascending aorta diameters for redilation events of the proximal arch were 47.15 mm (sensitivity: 76.0%; specificity: 62.0%) and 27.05 mm/m^2 (sensitivity: 73.9%, specificity: 62.0%) in the AAW and AAR groups, respectively. The preoperative ascending aorta diameter and BSA-indexed ascending aorta diameter were predictive factors for postoperative redilation of the proximal arch with areas under the curves of 0.703 (P = .014) and 0.682 (P = .041) in the AAW and AAR groups, respectively (Figure 5).

Table E1 shows aortic adverse events (rupture, dissection, and death). There were a few cases of dissection in the descending thoracic aorta: 2 (2.9%) in the wrapping

TABLE 5. Time-dependent Cox model for aortic adverse events with ascending wrapping (reference: aortic replacement = 0), chronic obstructive pulmonary disease, age, and aortic diameter in each aortic level

		95% CI		
Level of aorta	HR	Lower	Upper	*P* value
Annulus				
AAW	1.472	0.599	3.617	.3998
Annulus	1.109	1.007	1.222	.3604
Hypertension	0.201	0.023	1.787	.1501
Sex	1.064	1.013	1.116	.1260
Sinus				
AAW	1.442	0.589	3.529	.4225
Sinus	1.044	0.973	1.120	.2333
Hypertension	0.206	0.023	1.823	.1555
Sex	1.057	1.008	1.108	.2109
Ascending aorta				
AAW	1.469	0.568	3.797	.4275
Ascending aorta	1.003	0.936	1.075	.9310
Hypertension	0.194	0.0210	1.781	.1472
Sex	1.052	1.003	1.103	.3790
Proximal arch				
AAW	0.602	0.152	2.376	.4684
Proximal arch	1.349	0.930	1.501	.0253
Hypertension	0.112	0.009	1.381	.0876
Sex	1.049	0.991	1.109	.0968

HR, Hazard ratio; *CI*, confidence interval; *AAW*, ascending aortic wrapping.

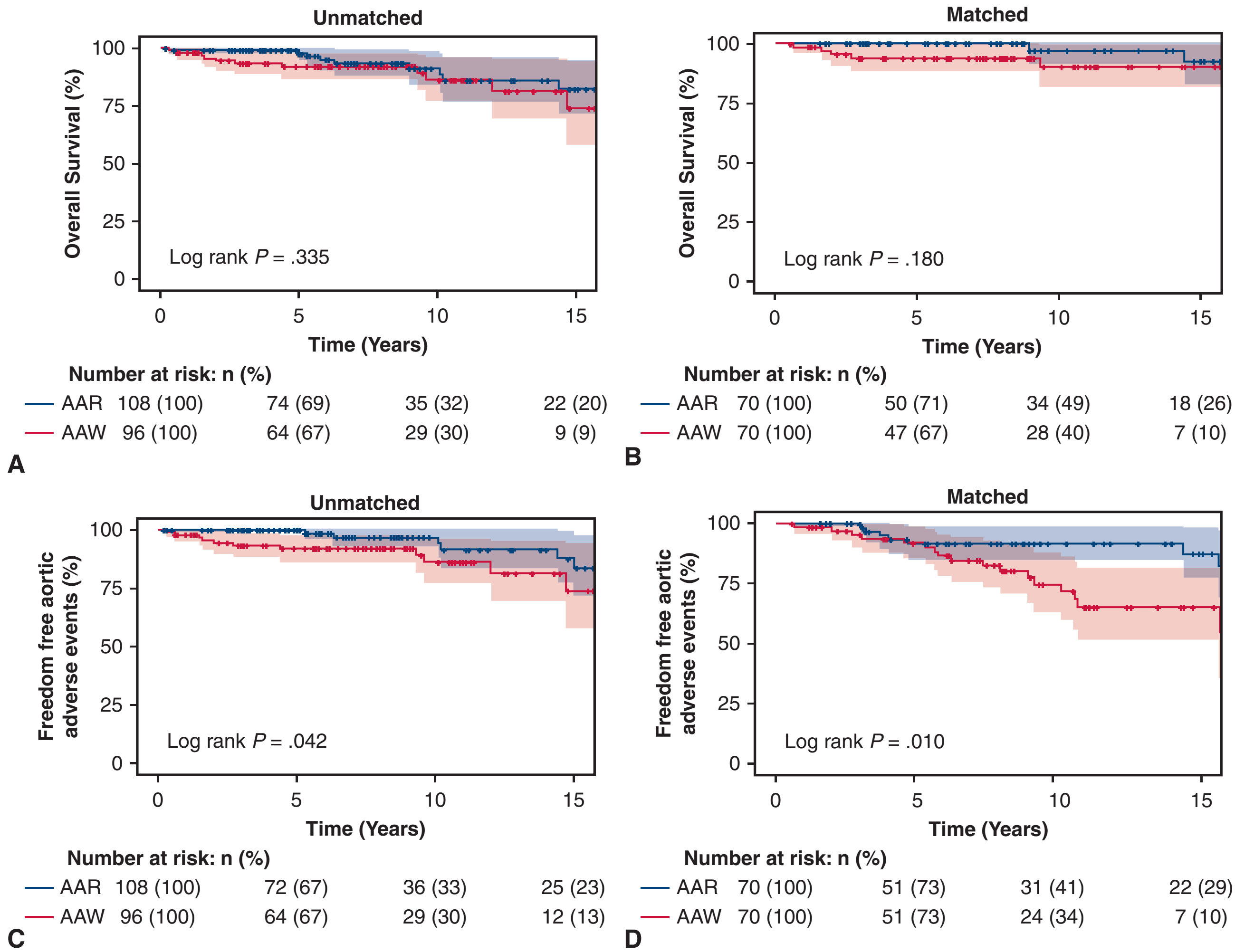

FIGURE 4. Kaplan–Meier plots of overall survival by group in (A) unmatched and (B) matched patients, and event-free survival in (C) unmatched and (D) matched patients. *AAR*, Aortic valve replacement; *AAW*, ascending aortic wrapping.

group and 1 (1.4%) in the replacement group. Interestingly, there was no root dissection or rupture case. Therefore, both AAW and AAR concomitant AVR may contribute to proximal part (root or sinus) stability.

DISCUSSION

In the present study, we conducted LMM to analyze the ascending aortic diameter at different 4 levels (annulus, sinus, ascending aorta, and proximal arch) after AAW and AAR. The distinct aortic diameter of each level was overall stable trend over time in both groups. However, we found that significant redilation occurred at the proximal aortic arch (0.343 mm/year, P = .006) in the AAW and that the proximal arch redilation was correlated with the preoperative mid-ascending aortic diameter. Furthermore, we demonstrated that the cutoff value for redilation of the proximal arch was 47.15 mm.

Real Benefit of Aortic Replacement in Moderately Dilated Ascending Aorta

Past investigations comparing AAW and AAR in patients with ascending arch disease have not resolved the controversy over which approach is preferable.[8] AAW is typically restricted to high-risk patients, making it difficult to evaluate any inherent benefits. Moreover, no randomized clinical trial has been devised to compare the 2 techniques. We tried to conduct comparative study, which have risk-adjusted data to overcome the selection bias using PS matching. When patients were assessed by serial echocardiography and CT, clinically relevant aneurysm formation or rapid expansion of the proximal aorta occurred more often in the AAW group than in the AAR group (17.1% vs 11.4%). Failure to stabilize the proximal arch in patients with AAW may lead to the risk of dilatation over time, which may potentially require additional surgery. Safety

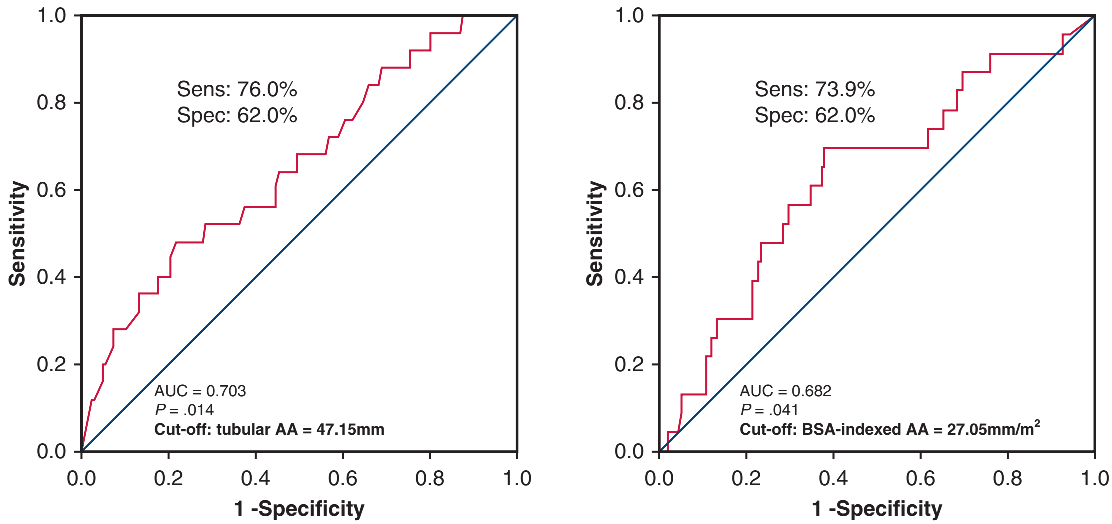

FIGURE 5. Receiver operating characteristic curves to determine cutoff values of postoperative redilation of the proximal arch for the (A) preoperative ascending aorta diameter and (B) BSA-indexed ascending aorta diameter. *Sens*, Sensitivity; *Spec*, specificity; *AUC*, area under the curve; *AA*, ascending aorta; *BSA*, body surface area.

profiles of ascending aorta replacement during AVR displayed excellent long-term results for a moderately dilated ascending aorta. For this reason, most surgeons prefer to perform AAW in patients aged more than 70 years and patients who have a limited life expectancy.

Progress of Proximal/Distal Portion of Ascending Aortic Surgery

Bauer and colleagues[9] and Akgun and colleagues[10] presented 4 cases of dislocation of the external wrapping due to aortic root dilation. Two redilatations reported in the study by Cohen and colleagues[13] occurred in patients who have a Dacron mesh to reinforce the ascending aortic wall. However, Plonek's[8] systematic review found no aortic root enlargement occurred after AAW when the external prosthesis was secured by proximal and distal fixation. Our investigation showed there was a slow rate of enlargement of the Valsalva (0.069 mm/year, $P = .524$) after AAW, and there was no significant event related to root enlargement after AAW. It may be related to the secure anchoring of the wrapping prosthesis to proximal portion. Although there were no adverse events noted in the aorta proximal to the AAW in our study, it should be recognized as a possible complication. We think that longer follow-up study about the safety of proximal portion after wrapping will be required.

More recent study showed both wrapping and graft replacement can be performed with favorable long-term clinical outcomes and quality of life.[14] However, in this study, we studied with a longer follow-up period (7.1 vs 4.9 years) and a larger number of patients (70 vs 20 in each group). Compared with the matched AAR group, the AAW group had a higher risk of long-term adverse aortic events (24.3% vs 14.3%, $P = .010$) in terms of postoperative redilation of distal portion, which means proximal arch in this study. To understand the impact of 2 therapeutic surgical procedures on the clinical aspects of the proximal arch's diameter and geometry, it is important to understand the characteristics of arch disease. When AAW is applied, it may be related to the unfavorable characteristics of arch angulation, proximal arch shape, high blood flow, and substantial pulsatile movement.

Three Possible Mechanisms of Redilation After Ascending Aortic Surgery

First, Emilie and colleagues[15] reported a significant increase in peak systolic shear stress in distal to the ascending aortic graft in patients who underwent AAR with AVR using 4-dimensional flow magnetic resonance imaging. They suggested that the enlargement may result from different hemodynamic stresses on the distinct aortic regions.[15] In the same manner, the present study demonstrated that the expansion over time at the distal to the AAW might be due to the major causes of different hemodynamic stress.

Second, the main concern among the adversaries of AAW is that it may cause degeneration of the wrapped portion of the aortic wall.[9,10,16] Histologic examination of the aortic wall underlying the reinforcement cuff revealed extensive wall degeneration. Dhillon and colleagues[17] observed late ruptures after wrapping of descending aorta aneurysms. Thus, tissue degeneration of aortic wall under wrapping material is a possible cause of redilation of the aortic arch after AAW.

Third, a recent study of abdominal aortic aneurysms found that segmental stiffening of the aorta preceded

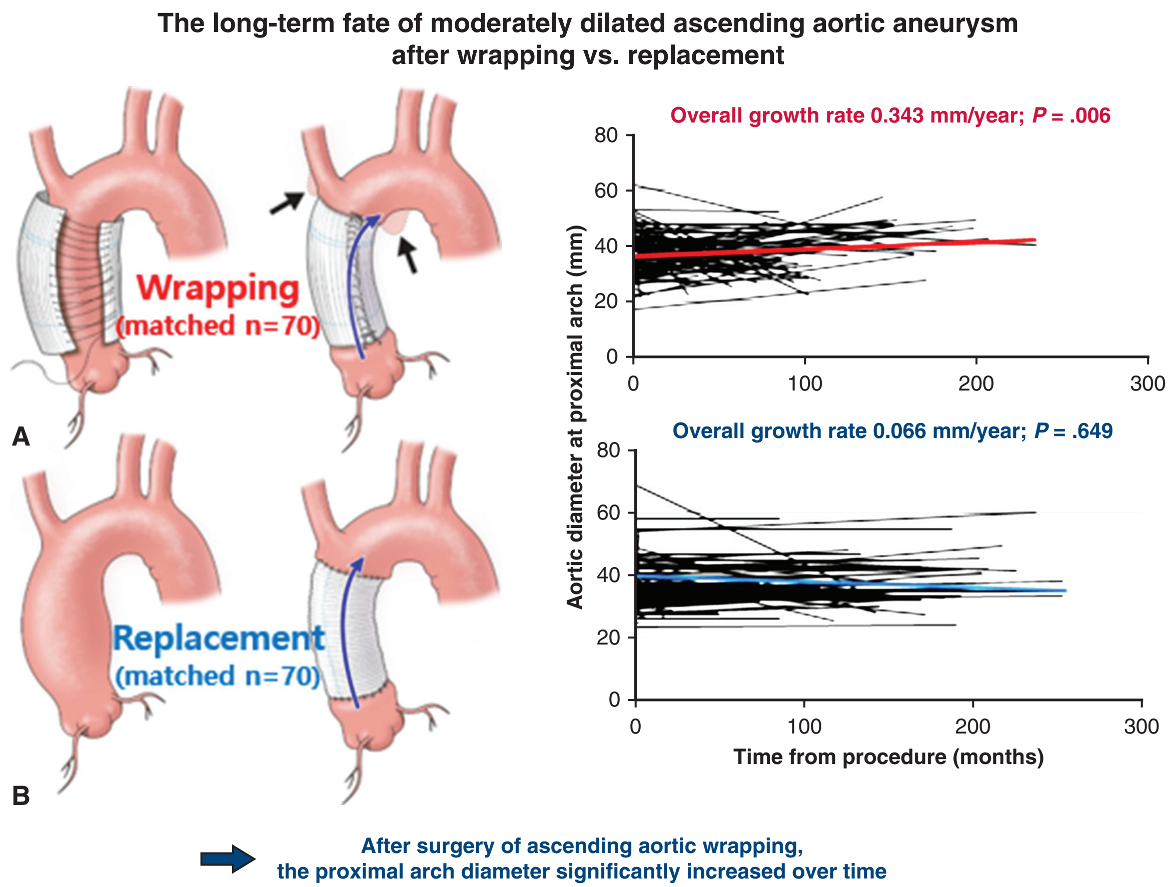

FIGURE 6. Ascending aortic procedure with (A) AAW (PTFE or double-velour vascular graft surrounded the native ascending aorta between the ST junction and the origin of the innominate artery) and (B) AAR (vascular grafts were used for replacement of the aorta, and anastomosis was done during circulatory arrest under moderate systemic hypothermia). *Blue arrow* represents the expected blood flow through the ascending aorta after surgery. After surgery of AAW, the proximal arch diameter significantly increased over time (*black arrow*).

aneurysm growth and introduced the concept that stiffening may act as an early mechanism triggering elastin breakdown and aneurysm growth.[18] Neri and colleagues[11] presented the histopathologic findings in those who needed a reoperation after AAW, which showed neovascular and cellular infiltration similar to a foreign-body reaction. Further, the evidence regarding cellular and molecular mechanisms for residual aortopathy after AAW remains complex, with the need for a larger cohort and well-controlled studies.

Cutoff Value of Aortic Diameter for Redilation of Proximal Arch

According to recent changes in the guidelines of the American College of Cardiology/American Heart Association criteria, the indication for an ascending aortic aneurysm associated with the bicuspid valve is 5.5 cm.[19] The European Society of Cardiology also published guidelines on the management of aortic disease, and these documents contained more conservative recommendations for bicuspid aortopathy.[20] Surgery should be performed for Marfan syndrome and a maximal ascending aorta diameter greater than 50 mm. However, the management of a moderately dilated ascending aorta remains controversial. We investigated the different changes observed in patients who underwent surgery according to the type of procedure (AAW or AAR) and suggested a cutoff value for the preoperative diameter of the ascending aorta related to high-risk redilation. These findings may improve the understanding of the effects of the different procedures and provide guidance to help surgeons decide between AAW and AAR during AVR.

Study Limitations

This study was limited by its retrospective nature. This study was conducted at a single center; therefore, the findings may not be generalizable to other populations. Furthermore, there were differences in the patients' characteristics between the groups. To adjust the risk factors and reduce selection bias, we used PS matching but also unidentified confounding factors that might have influenced the results despite this correction. Another important limitation of this study was that the surgeons selected the procedures. The sample size becomes too low in such a categorization and provides statistically insufficient results. We derived the cutoff for redilation using the receiver operating characteristic curve, but the area under the curve value was relatively low, which can be interpreted as a result that does not show sufficient correlation. We did not conduct quantitative analysis for the phenotype of the ascending aorta. The minimal diameter difference of the AAW material compared with the AAR graft diameter could affect the late transverse arch dilatation. Furthermore, we have not conducted an analysis on the descending thoracic aorta. Last, the number of patients with connective tissue disease was too small for a subgroup analysis.

CONCLUSIONS

Both AAW and AAR led to stabilization of the dilated aorta, with acceptable long-term durability. However, the diameter of the proximal arch significantly increased over time in patients with AAW and an ascending aortic diameter greater than 47.15 mm (Figure 6). Therefore, the results of this study suggest that the proximal arch after AAW should be under careful surveillance to assess aortic redilation.

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.

The authors thank Dong-Su Jang, MFA (medical illustrator), for help with the illustrations, and Hye Jung Shin, MS (biostatistics collaboration unit, Yonsei University College of Medicine), for statistical analysis.

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Key Words: aortic aneurysm, aortic replacement, aortic valve replacement, aortic wrapping, ascending aorta

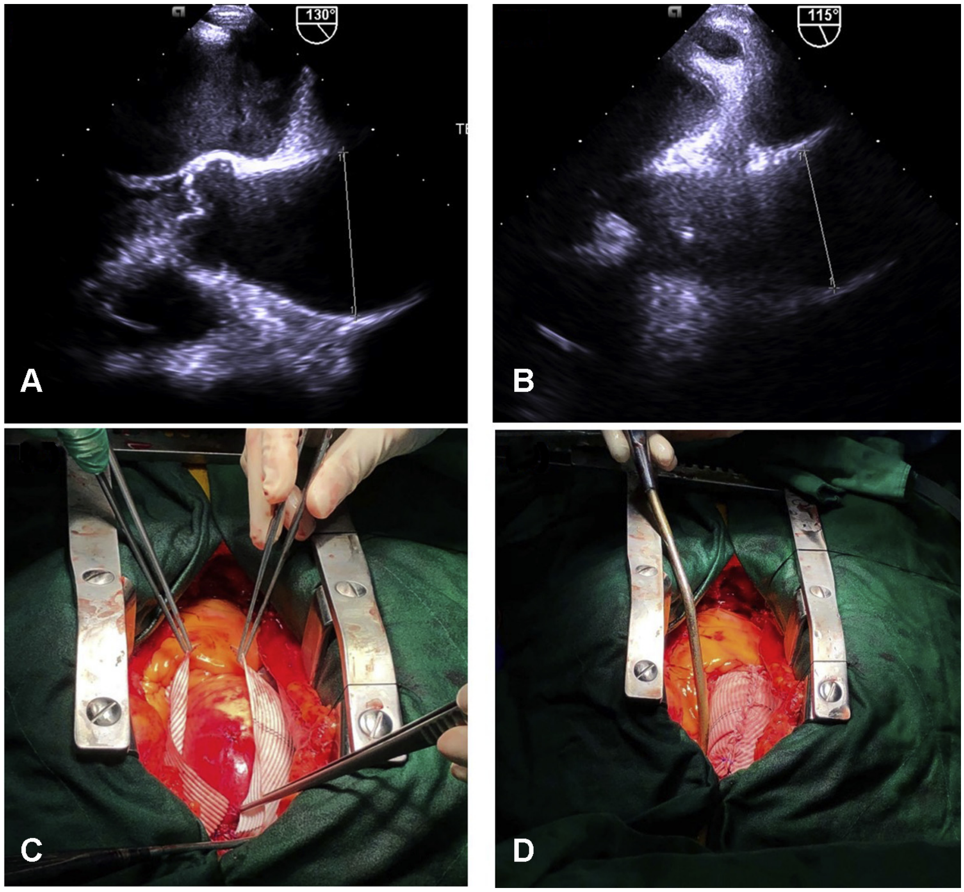

FIGURE E1. Intraoperative transesophageal echocardiography before (A) and after (B) AAW. The real filed pictures before (C) and after (D) AAW.

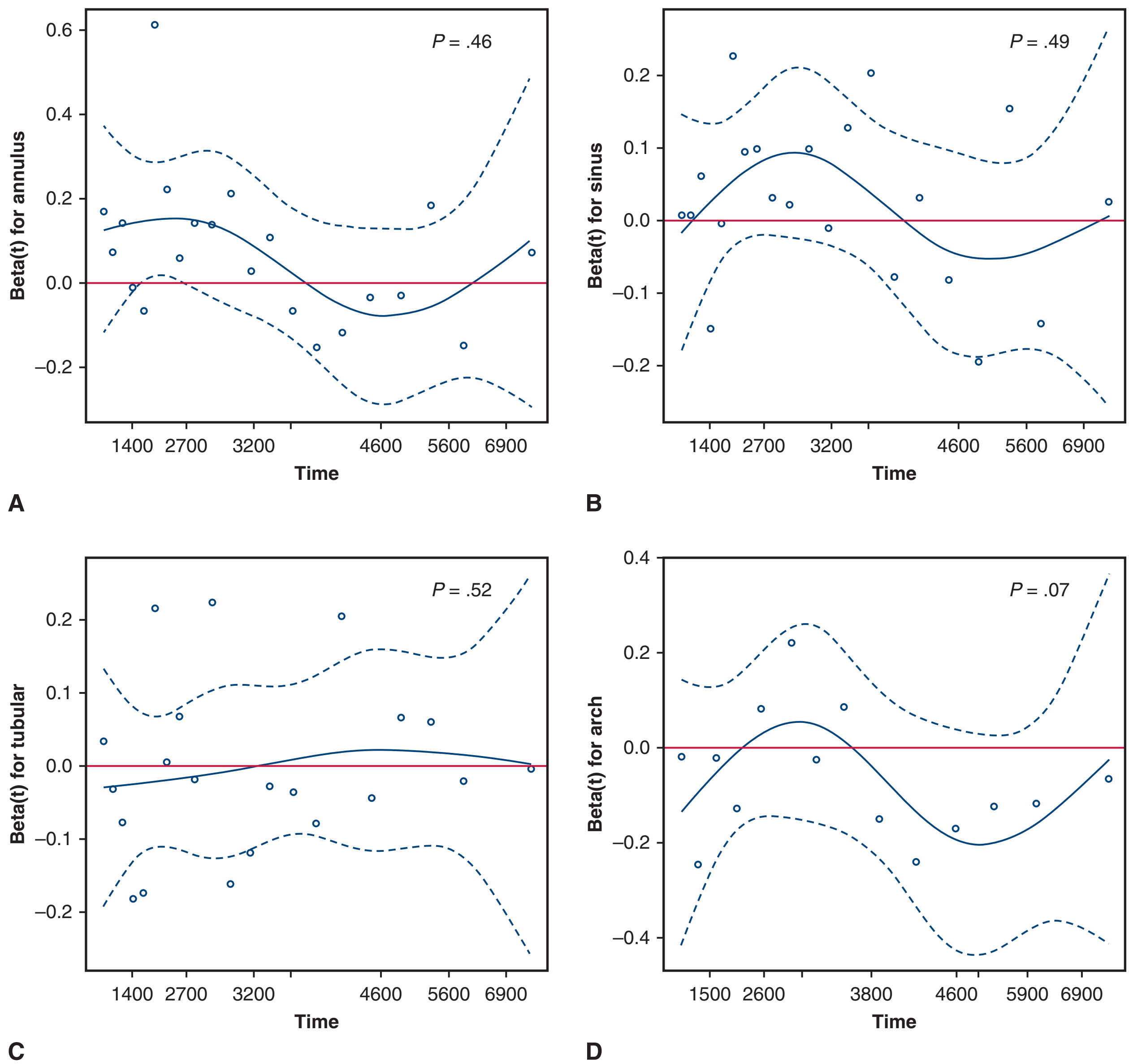

FIGURE E2. The cox.zph plot was used to estimate of time-dependent coefficients. The hazards over time of annulus, sinus, ascending aorta, and proximal arch were all nonsignificant ($P > .05$). Annulus (A), sinus (B), ascending aorta (C), and proximal arch (D).

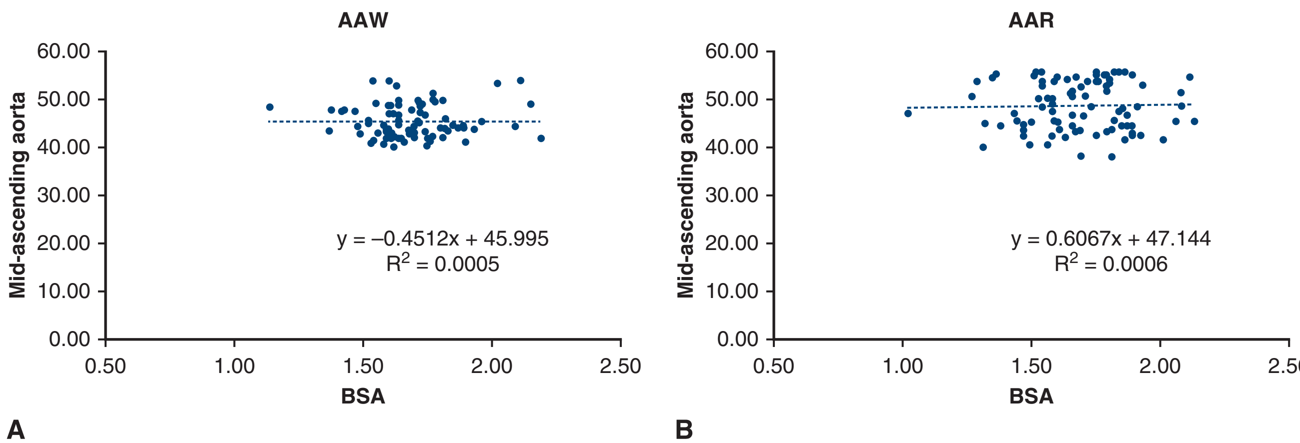

FIGURE E3. The mid-ascending aortic diameter according to BSA in AAW (A) and AAR (B). BSA was not significantly related to mid-ascending aorta in this study population. *AAW*, Ascending aortic wrapping; *AAR*, ascending aortic replacement; *BSA*, body surface area.

ADULT

TABLE E1. Postoperative late outcomes in terms of aortic adverse events after aortic wrapping and replacement

	AAW (N = 70)	AAR (N = 70)	*P* value
Total aortic adverse events	17 (24.3%)	10 (14.3%)	.010
Reoperation of ascending or arch aorta	8 (11.4%)	4 (5.7%)	.366
Dissection or rupture	10 (14.3)	6 (8.6)	.227
Anatomic locations of dissection			
Root	0	0	-
Arch	8 (11.4)	5 (7.1)	.117
Descending aorta	2 (2.9)	1 (1.4)	.584
Redilation of proximal arch	12 (17.1%)	8 (11.4%)	.235

AAW, Ascending aortic wrapping; *AAR*, ascending aortic replacement.

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