Late complications after hybrid aortic arch repair

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ABSTRACT

Objective: Although hybrid arch repair has gained widespread application as an alternative option for high-risk patients, concerns about its long-term durability remain an important issue. The aim of this study was to investigate late complications after hybrid arch repair.

Methods: From January 2002 to December 2017, hybrid arch repair was performed in 65 patients with aortic arch disease (median age, 66.1 years; range, 41-86 years). Hybrid arch repair was defined as debranching involving at least one supra-aortic vessel bypass and simultaneous or staged endovascular thoracic stent grafting. We retrospectively analyzed late complications including reintervention, open conversion, and aortic-related death. The median follow-up period was 60.1 months (range, 1-170 months).

Results: The in-hospital mortality rate was 6% (4/65). Except for early death (n = 4) and early open conversion (n = 2), late complications were observed in 25 patients (25/59 [42%]). The median time interval between the initial procedure and late complication was 36.6 months (range, 1-92 months). Late complications included delayed type I endoleak (n = 8), distal stent-induced new entry (n = 3), stent migration (n = 3), retrograde type A dissection (n = 2), aortopulmonary fistula (n = 2), aortoesophageal fistula (n = 1), stent fracture (n = 1), infection (n = 1), and sudden death (n = 4). Six of these patients (10%) underwent late open conversion. The overall survival rates at 3 years and 6 years were 71.1 ± 7.4% and 57.2 ± 11.3%, respectively. The aortic event-free rates at 3 years and 6 years were 52.1 ± 7.3% and 39.4 ± 10.3%, respectively.

Conclusions: Late complications in hybrid arch repair occurred in a substantial proportion of patients during midterm follow-up. Regardless of zone type, the incidence of late complications was relatively high. This study suggests that timely reintervention and open conversion are important for rescuing patients, but repeated reinterventions and conservative strategies are not recommended. Aggressive management and life-long surveillance after hybrid arch repair are mandatory for better outcomes. (J Vasc Surg 2019;70:1023-30.)

Keywords: Late complication; Hybrid arch repair; Aortic arch

Owing to accumulated experience and technical evolution in recent years, endovascular procedures for aortic diseases have been expanded for different indications and have gained widespread adoption. In particular, hybrid arch repair, which is defined as a procedure that combines debranching of supra-aortic branch vessels with stent grafting of the aortic arch, was introduced as an alternative option that does not require circulatory arrest and hypothermia,[1,2] Some reports have shown comparable early results for high-risk patients.[3,4]

However, concerns about long-term durability with this emerging treatment modality remain unresolved. Various complications such as endoleak, retrograde type A dissection (RTAD), infection, stent migration, and fistula have been reported to develop through the long period after thoracic endovascular aortic repair (TEVAR) as well as in the early period.[5-8] Moreover, the incidence of reintervention for arch endograft is reported to be higher than that of isolated TEVAR.[5-7] It is recognized that the anatomic nature of the arch that is involved in angulation, high blood flow, and substantial pulsatile movement contributes to the risks surrounding the initial procedure and its late events. These findings suggest that further investigation of late complications after hybrid arch repair is necessary for the proper assessment of its safety and suitability.

Although several studies have reported complications after hybrid arch repair, there are still limited data on late complications obtained through long-term follow-up.[5,6,8] Therefore, the aim of this study was to investigate late complications after hybrid arch repair.

METHODS

Patients

This retrospective study was conducted after approval by the Institutional Review Board of the Yonsei University College of Medicine (IRB approval number:

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No. 4-2014-0810), and a waiver of consent was obtained. From January 2002 to December 2017, 342 patients underwent conventional surgical or hybrid endovascular repair for aortic arch diseases at the Yonsei Cardiovascular Hospital of Yonsei University Health System in Seoul, Korea. Hybrid arch procedures were performed in 65 of these patients. Patients who underwent supra-aortic branch revascularization (debranching) and simultaneous or staged endovascular thoracic stent grafting were included. Patients undergoing staged TEVAR after total arch replacement with the elephant trunk technique were excluded. The indications for hybrid arch repair included thoracic aortic aneurysm (n = 36), type B aortic dissection involving the distal arch (n = 25), and arch ulcer/intramural hematoma (n = 4). As a prerequisite for successful stent graft placement, patients were required to have a proximal landing zone of healthy and nondissected aorta (or polyester graft) of at least 20 mm along the curvature of the aortic arch and a diameter of less than 40 mm at the level of the proximal landing zone. The decision for hybrid arch repair was based on discussions among cardiac surgeons, vascular surgeons, interventional cardiologists, and vascular radiologists.

Operative technique

Surgical debranching. The operation was performed under general endotracheal anesthesia with continuous transesophageal echocardiography, cerebral oxygen saturation (rSO_2), and arterial pressure monitoring. Ten patients (15%) underwent the procedure in one stage and 55 patients (85%) underwent the procedure in two stages. In cases involving two stages, TEVAR was performed after full recovery from cervical debranching. Complete debranching was performed through a median sternotomy. After the induction of pharmacologic hypotension (systolic blood pressure <90 mm Hg), the ascending aorta was partially clamped with a side-biting clamp, and the proximal end of a prosthetic graft was sutured end-to-side to the aorta. Left subclavian artery (LSCA) revascularization was performed when possible, but in cases in which it was difficult to expose, the LSCA was selectively ligated after communication with the vertebral artery was confirmed. Cervical debranching was performed through cervicotomies and consisted of a supratracheal right carotid-to-left common carotid artery bypass using a GORE-TEX (W. L. Gore & Associates, Flagstaff, Ariz) 8-mm graft or 8-mm Dacron graft. Carotid clamping was performed under rSO_2 monitoring, and no cases required a carotid shunt.

Endovascular procedure. All TEVARs were performed in a hybrid room containing both endovascular and surgical equipment. The operation was performed under intravenous sedation without general endotracheal anesthesia and with continuous rSO_2 and arterial pressure monitoring. TEVAR was performed simultaneously or immediately after full recovery from cervical debranching. Debranching and TEVAR were performed within a median interval of 1.8 days (range, 0-7 days) between debranching and stent graft placement. Spinal fluid drainage before TEVAR was used for selected patients who underwent long segment coverage over the eighth intercostal space level and were at increased risk for paraplegia. The stent types used for TEVAR in the hybrid group included Valiant (n = 31; with the Captivia delivery system; Medtronic, Santa Rosa, Calif), Seal (n = 20; S&G Biotech Inc, Seoul, Republic of Korea), and Cook TX2 devices (n = 14; Cook Medical Inc, Bloomington, Ind).

ARTICLE HIGHLIGHTS

- **Type of Research:** Retrospective single-center cohort study
- **Key Findings:** Late complications occurred in 42% of 65 patients who underwent hybrid arch repair and included delayed type I endoleak (n = 8), retrograde type A dissection (n = 2), and sudden death (n = 4), among others. The aortic event-free rates at 3 years and 6 years were 52.1% and 39.4%, respectively.
- **Take Home Message:** Almost one-half of the patients who underwent hybrid arch repair experienced late aortic complication, including delayed type I endoleak, proximal dissection, and aorta-related and sudden death. Surveillance and timely reintervention including open conversion are important for rescuing these patients.

Definitions

A late complication was defined as a complication that developed more than 30 days after the initial TEVAR, except for early complications such as technical failure, iatrogenic injury, and perioperative infection. The EuroSCORE II system was used to assess operative risks (http://www.euroscore.org/calc.html). Previous cardiac surgery was defined as history of open heart surgery including off-pump coronary bypass surgery via median sternotomy. Spinal cord ischemia was defined as any new lower extremity deficit that was unrelated to an intracerebral event. Stroke was defined as any new global or focal neurologic deficit lasting more than 24 hours with an acute lesion on brain imaging. A reintervention was defined as any surgical or endovascular procedure for any complication related to the aorta after the initial procedure.

Data collection and follow-up

Preoperative and perioperative data were collected prospectively from the cardiac and vascular research databases at our institution. Detailed data on late complications and long-term survival were obtained by hospital chart review or telephone interview. Information

Table I. Patient characteristics

Variables	All (N = 65)	Zone 0 (n = 19)	Zone 1 (n = 13)	Zone 2 (n = 33)	*P* value
Age, years	66.7 ± 14.5	65.9 ± 14.9	71.9 ± 12.3	63.1 ± 14.9	.243
Male sex	55 (87)	15 (79)	11 (20)	29 (88)	.691
Smoking	35 (54)	9 (47)	9 (69)	17 (54)	.442
Hypertension	49 (75)	15 (79)	7 (54)	27 (82)	.128
Diabetes	12 (19)	3 (16)	4 (31)	5 (15)	.441
CAOD	25 (39)	6 (32)	9 (69)	10 (30)	.039
Old CVA	9 (14)	2 (11)	2 (15)	5 (15)	.883
COPD	9 (14)	3 (16)	1 (8)	5 (15)	.771
LVEF, %	60.2 ± 5.1	60.6 ± 5.5	59.6 ± 3.3	60.3 ± 4.3	.912
eGFR	71.0 ± 25.7	69.7 ± 25.8	72.1 ± 23.1	71.1 ± 27.3	.950
Aneurysm size, mm	58.7 ± 12.2	60.7 ± 12.7	60.5 ± 10.8	56.6 ± 12.5	.467
Aortic pathology					.023
Degenerative aneurysm	39 (60)	11 (58)	12 (92)	16 (49)	
Dissection	26 (40)	8 (42)	1 (8)	17 (52)	
Previous aortic surgery	11 (17)	6 (32)	4 (31)	1 (3)	.010
Rupture	2 (3)	1 (5)	1 (8)	0 (0)	.320
Urgent/emergency	6 (9)	4 (21)	0 (0)	2 (6)	.087
EuroScore II	13.3 ± 8.4	13.1 ± 10.2	13.2 ± 6.4	13.5 ± 8.1	.951

CAOD, Coronary artery occlusive disease; *COPD*, chronic occlusive pulmonary disease; *CVA*, cerebrovascular accident; *eGFR*, estimated glomerular filtration rate; *EuroSCORE II*, European System for Cardiac Operative Risk Evaluation; *LVEF*, left ventricular ejection fraction.
Values are presented as mean ± standard deviation or frequencies (%).

on death was obtained from the database of the Korea National Statistical Office. Follow-ups were complete for 98% of patients. Follow-up protocols included clinical examinations and computed tomography scans before discharge, which were performed at 6 months and annually thereafter. The median follow-up period was 60.1 months (range, 1-170 months).

Statistical analyses

Statistical analyses were performed with SPSS 18.0 (SPSS Inc, Chicago, Ill). All data were expressed as mean ± standard deviation, frequency, or percentage. Continuous variables were compared using a Student *t*-test, and categorical variables were compared using the χ^2 or Fisher's exact test, as appropriate. Best fit was assessed using the Hosmer and Lemeshow χ^2 test. Long-term survival and freedom of reintervention curves were estimated using the Kaplan-Meier method. Statistical significance was defined as a two-tailed *P* value of less than .05.

RESULTS

Patient characteristics. The median age was 66.1 years (range, 41-86 years). Eleven patients (17%) had a history of previous cardiac surgery. Zone 1 patients had a significantly higher proportion of coronary artery occlusive diseases (69%). Six patients (9%) were treated as emergency cases. The mean maximal aneurysm size was 58.7 ± 12.2 cm. Forty percent of patients exhibited dissection pathology. The mean EuroScore II was 13.3 ± 8.42. Patient demographics are presented in Table I.

Operative details. The following types of hybrid arch repair were performed: total cervical debranching (n = 19), carotid-carotid-LSCA bypass (n = 12), carotid-carotid bypass (n = 1), carotid-LSCA bypass (n = 32), and carotid-LSCA interposition (n = 1). LSCA revascularization was performed in 61 patients (94%), and staged procedures were conducted in 55 patients (78%). Preoperative drainage of cerebrospinal fluid was performed in eight patients (12%). The mean operative time was 217.8 ± 76.1 minutes, and the median number of stents placed per patient was 1.8 (range, 1-3).

Perioperative complications. The overall in-hospital mortality rate was 6% (4/65). The in-hospital mortality rates for zones 0, 1, and 2 were 11% (2/19), 8% (1/13), and 3% (1/33), respectively. Causes of death were aortic rupture (n = 2), sepsis owing to pneumonia (n = 1), and major stroke (n = 1). The stroke rate was 8% (5/65), and there were no differences among zone types. Most complications occurred during the TEVAR procedure. The early outcomes are summarized in Table II. The old age (hazard ratio [HR], 1.130; 95% confidence interval [CI], 1.002-1.301; *P* = .039), zone type (zone 0 vs others; HR, 4.680; 95% CI, 1.012-21.680; *P* = .048), and chronic kidney disease (HR, 6.764; 95% CI, 1.405-32.564; *P* = .017) were independent risk factor of perioperative mortality and morbidity (Supplementary Table I, online only).

Late complications. Of the 59 survivors, except for early death (n = 4) and early open conversion (n = 2), 25 patients (42%) experienced late complications. There

Table II. Perioperative mortality and morbidity

Variables	All (N = 65)	Zone 0 (n = 19)	Zone 1 (n = 13)	Zone 2 (n = 33)
Hospital mortality	4 (6)	2 (11)	1 (8)	1 (3)
Technical failure	2 (3)	1 (5)	1 (8)	
Open conversion	2 (3)	1 (5)	1 (8)	
Morbidities				
Debranching stage	4 (6)	3 (16)	1 (8)	
Stroke				
Paraplegia				
Renal failure	1 (2)	1 (5)		
Lung complication	3 (5)	2 (11)	1 (8)	
RTAD				
Endovascular stage	16 (25)	8 (42)	3 (23)	5 (15)
Stroke	5 (8)	2 (11)	1 (8)	2 (6)
Paraplegia				
Renal failure	4 (6)	2 (11)	1 (8)	1 (3)
Lung complication	6 (9)	3 (16)	1 (8)	2 (6)
RTAD	1 (2)	1 (5)		

RTAD, Retrograde type A dissection.
Values are presented as number (%).

was no difference in incidence of late complications in patients with one-stage vs two-stage procedures (40% vs 38%; $P = .91$; Supplementary Table II, online only). Eight patients (14%) exhibited delayed type I endoleaks. Seven of the eight patients experienced proximal endoleaks (type IA). The reasons for proximal endoleak (type IA) included the short length of the landing zone (n = 3), steep angulation (n = 2), and progression of the aortic lesion to the arch (n = 2). Patients in the zone 1 group had a higher proportion of type I endoleak (27%) compared with the zone 0 and zone 2 groups. Five patients underwent reintervention, and three patients underwent late open conversion. Two patients underwent delayed RTAD, which occurred at 30 and 92 months after TEVAR. Furthermore, aortopulmonary fistula (APF) developed in two patients, and aortoesophageal fistula (AEF) developed in one patient. One patient survived after elective late open conversion surgery. A second patient visited the emergency room with symptoms of severe pneumonia, was later diagnosed with APF, and died after conservative care. Another patient with AEF died owing to an inoperable condition. Detail and modes of late complications after hybrid arch repair are summarized in Table III and Fig 1.

The overall incidence of late complications according to the used stent graft type did not differ (Valiant, 39%; Seal, 40%; Cook TX2, 37.5%).There was no difference between the stent grafts with regard to RTAD and SINE, but small numbers limited the analysis (Supplementary Table III, online only).

Sudden death occurred in four patients during the follow-up period. Six patients (9%) underwent late open conversion for RTAD (n = 2), uncontrolled type IA endoleak (n = 1), distal stent graft-induced new entry (n = 1), stent migration (n = 1), and APF (n = 1). All patients who underwent conservative care for stent failure died. The total incidence of late complications was higher in zone 0 and zone 1 than in zone 2 (56% and 55% vs 30%, respectively; Table IV).

The overall survival rates at 3 years and 6 years were 71.1 ± 7.4% and 57.2 ± 11.3%, respectively (Fig 2, *A*). The aortic event-free rates at 3 years and 6 years were 52.1 ± 7.3% and 39.4 ± 10.3%, respectively (Fig 2, *B*).

Clinical course of hybrid arch repair (acute and late complications). Of all patients (n = 65) who underwent hybrid arch repair, six patients experiences acute fatal complications, including in-hospital mortality (n = 4) and open conversion (n = 2). During the median follow-up period of 60 months, 34 patients maintained a stable clinical course and 25 patients underwent late complications. Except for four patients with sudden death, 21 patients with late complications had treatments including reintervention (n = 12), open conversion (n = 6), and conservative care (n = 3). Of 12 patients with reintervention, 9 patients survived and 3 patients died. Of six patients with late open conversion, five patients survived and one died. All patients who had conservative care did not survive. The clinical course including acute and late complications of hybrid arch repair is summarized in Fig 3.

DISCUSSION

Results from this investigation show that the overall complication rate of hybrid arch repair including acute and late complications was 48% (31/65). Only one-half

Table III. Late complications of hybrid arch repair (except early conversion and death)

Variables	All (N = 59)	Zone 0 (n = 16)	Zone 1 (n = 11)	Zone 2 (n = 32)
Late aorta-related mortality	10 (17)	6 (38)	2 (18)	2 (6.)
Total late complication	25 (42)	9 (56)	6 (55)	10 (30)
Delayed type I endoleak	8 (14)	2 (13)	3 (27)	3 (9)
Ia endoleak	7 (12)	2 (13)	2 (18)	3 (9)
Ib endoleak	1 (2)		1 (9)	
RTAD	2 (3)		1 (9)	1 (3)
Stent migration	3 (5)	1 (6)	1 (9)	1 (3)
Stent fracture	1 (2)	1 (6)		
SINE	3 (5)	1 (6)		2 (6)
APF	2 (3)	1 (6)		1 (3)
AEF	1 (2)			1 (3)
Stent infection (rupture)	1 (2)	1 (6)		
Sudden death	4 (7)	2 (11)	1 (9)	1 (3)
Late open conversion	6 (9)		1 (9)	5 (16)
Bypass graft occlusion	–	–	–	–

AEF, Aortoesophageal fistula; *APF,* aortopulmonary fistula; *RTAD,* retrograde type A dissection; *SINE,* distal stent graft-induced new entry.
Values are presented as number (%).

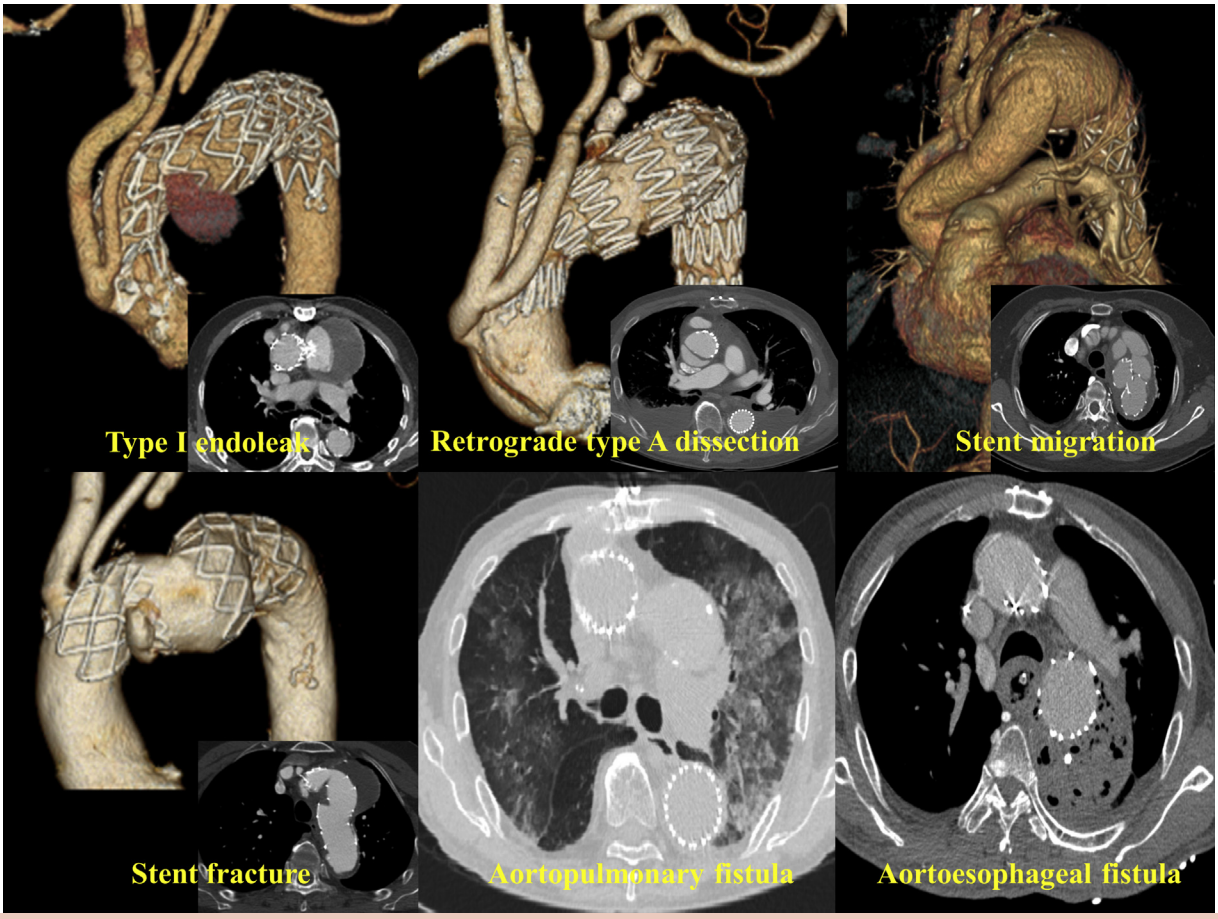

Fig 1. Modes of late complications after hybrid arch repair.

of the patients remained stable after hybrid arch repair. The other half experienced late aortic events, including reintervention, open conversion, aorta-related death, and sudden death during the follow-up period. Regardless of zone type, the incidence of late complications was relatively high.

Although early mortality and complications after hybrid arch repair have been reported in various studies, less is

Table IV. Details of mortality and open conversion for stent failure

Patient	Sex	Age, years	Disease	Interval, months	Hybrid type	Cause of failure	Management	Outcome
1	M	54	Aneurysm	72	LCCA-LSCA	Type IA endoleak	Open conversion (DTA replacement)	Survival
2	M	78	Aneurysm	72	Total debranching	Type IA endoleak	Death during wait for surgery	Death
3	M	80	Aneurysm	5	RCCA-LCCA-LSCA	RTAD	Open conversion (ascending replacement)	Death
4	F	75	Dissection	9	LCCA-LSCA	RTAD	Open conversion (total arch)	Survival
5	M	60	Aneurysm	12	LCCA-LSCA	Stent migration	Open conversion (DTA replacement)	Survival
6	M	70	Dissection	65	Total debranching	Stent fracture	Conservative care	Death
7	M	69	Dissection	51	LCCA-LSCA	SINE	Open conversion (DTA replacement)	Survival
8	M	83	Aneurysm	48	Total debranching	APF	Conservative care	Death
9	M	75	Aneurysm	39	LCCA-LSCA	APF	Open conversion (total arch + omentum)	Survival
10	M	79	Aneurysm	18	LCCA-LSCA	AEF	OP refuse	Death
11	M	80	Dissection	36	Total debranching	Infection	Re-TEVAR conservative care	Death

AEF, Aortoesophageal fistula; *APF*, aortopulmonary fistula; *DTA*, descending thoracic aneurysm; *LCCA*, left common carotid artery; *LSCA*, left subclavian artery; *RCCA*, right common carotid artery; *RTAD*, retrograde type A dissection; *SINE*, distal stent graft-induced new entry; *TEVAR*, thoracic endovascular aortic repair.

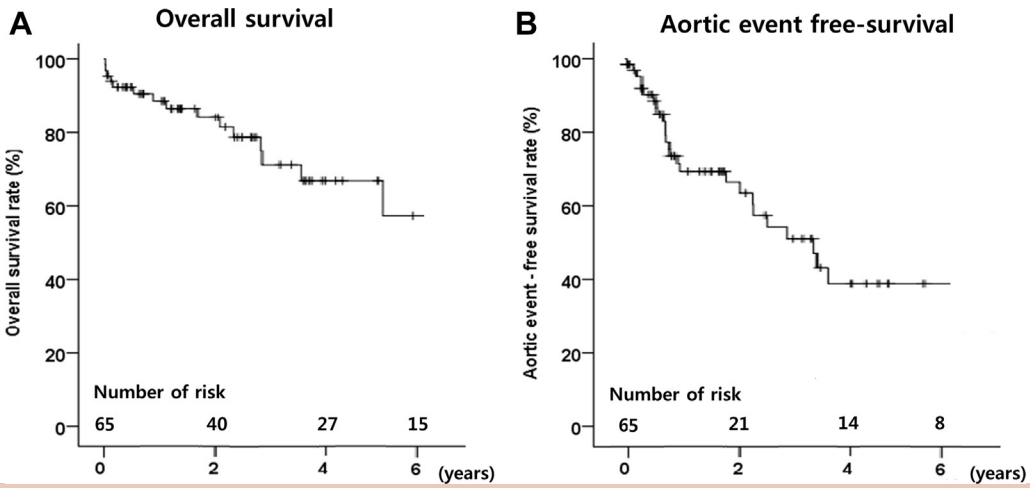

Fig 2. Overall survival rates **(A)** and aortic event-free survival rates **(B)** of hybrid arch repair.

known about late complications. Geisbüsch et al[5] reported that, during a mean follow-up period of 21.4 months, the reintervention rate was 27%, and 6% of patients underwent late open conversion.[5] According to short-term data from Tokuda et al,[8] 22% of the hybrid group (13/58) had aortic-related events during a mean follow-up period of 15.5 months. Our study showed a higher incidence of late complications (25/59 [42%]) over a median follow-up period of 60.1 months (Fig 3). This outcome was possibly due to a longer follow-up period and the inclusion of aortic events, such as sudden death. These findings imply that a longer follow-up period could be associated with a higher incidence of late complications after hybrid arch repair.

A representative mode of late complication is the proximal type I endoleak. In comparison with isolated TEVAR procedures, arch lesions are known to be more prone to type I endoleak, with a reported incidence of 15% to 25%,[2,9] Our study also showed a high incidence of type I endoleak. At 60.1 months of follow-up, eight patients (13.6%) exhibited delayed type I endoleaks. We found that the type I endoleaks were mostly associated with

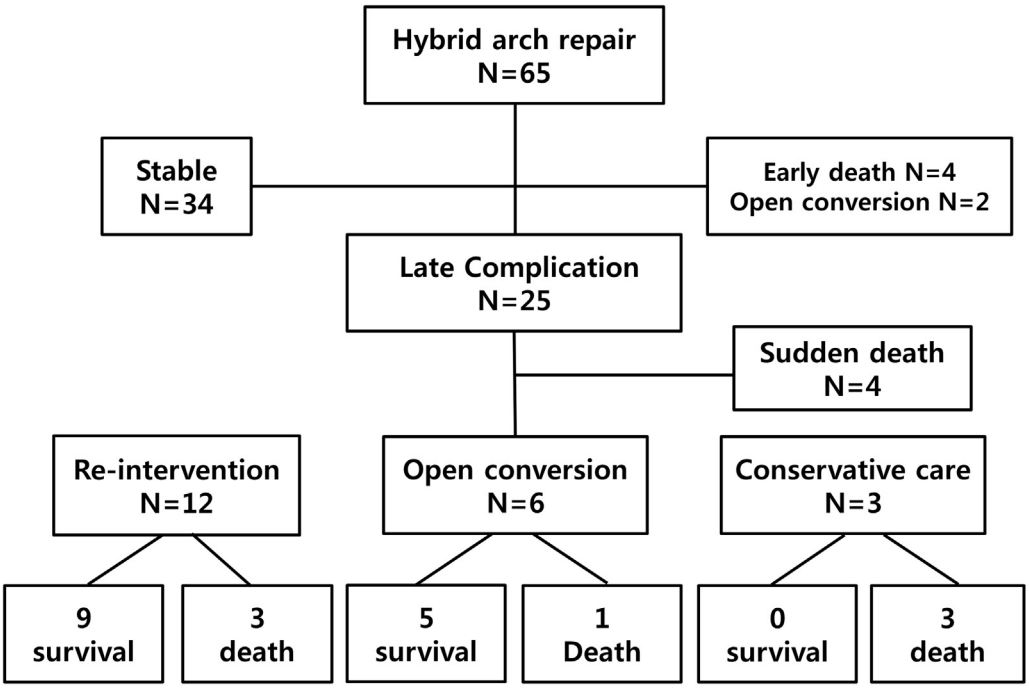

Fig 3. Clinical course of hybrid arch repair during a mean follow-up period of 60.1 months.

a proximal lesion next to the distal arch. In addition, the zone 1 group had a higher incidence of type IA endoleak (27% vs 13%). This finding suggests that a more aggressive positioning toward proximal zone 0 may be beneficial in terms of preventing type IA endoleak.

Another important issue of late complication after hybrid arch repair is delayed RTAD. According to a meta-analysis from Chen et al,[10] the incidence of RTAD after TEVAR is 2.5% with a mortality rate of 37.1%. In the current study, two patients underwent RTAD during the late period. Interestingly, RTAD can develop at various time points after the initial hybrid procedure. Two RTADs occurred at 30 and 92 months after TEVAR. All RTADs developed in patients who had undergone hybrid repair for chronic dissection. Mosquera et al[11] reported a similar case of late RTAD at 7 months after hybrid arch repair for type B intramural hematoma. Therefore, careful follow-up for late RTAD seems to be more necessary in patients undergoing hybrid arch repair for dissection pathologies.

APF or AEF has been shown to be rare (incidence of 0%-1%), but fatal, after hybrid arch repair.[12] In our study, APF and AEF were not rare (3/65 [5%]). Similar to other studies, the outcomes related to APF and AEF in our study were very poor (mortality of 2/3 [67%]). Most patients died after conservative care for inoperable conditions. Because patients with APF or AEF had visited nonvascular clinics with respiratory or gastrointestinal symptoms, proper time for surgery was subsequently lost.

The main factor of late complications developed from the endovascular procedure, and not the debranching procedure. Benedetto et al[13] have reported the long-term stability of bypass grafts in cervical debranching. We also found no problems associated with cervical bypass occlusion and stenosis during the follow-up period. This finding demonstrates that late complications after hybrid arch repair were associated with the arch endograft.

It is important to note that late complications after hybrid arch repair developed at various times after the initial procedure. The median interval was 36.6 months between the initial procedure and the development of late complications; this ranged from 1 to 92 months. Eight patients did not experience any complications during the 5-year follow-up period, but later experienced delayed type I leak and RTAD at 6 to 8 years after the initial procedure. The delayed occurrence of late complications following hybrid arch repair has been reported.[5,8,14] It is thought that aortic arch-related characteristics and properties, including angulation, high-velocity blood flow, and substantial pulsatile movement, may be an inherent weak point of hybrid arch repair; this weak point may be associated with endoleaks, RTAD, and distal stent graft-induced new entry. This finding suggests that the long-term stability of hybrid arch repair cannot be guaranteed.

During the follow-up period, four patients (6.8%) died suddenly. All of them had arch aneurysm disease without any cardiac or respiratory disease. Moreover, APF and AEF initially presented as respiratory or gastrointestinal symptoms and were, therefore, misdiagnosed as other diseases. These findings show that many hybrid

arch repair patients can experience aorta-related events and sudden death, which may be mistaken for other diseases. These findings suggest that the long-term survival and quality of life of hybrid arch repair may decrease upon longer follow-up periods.

The management of late complications after hybrid arch repair is extremely important. Twelve patients (19%) in the hybrid group underwent endovascular reintervention. Six patients (9%) underwent late open surgery for various causes, including endoleaks, new dissection, stent migration, and infection. Our study revealed that many endoleaks were resolved by reintervention, and death occurred in some patients during repeated reintervention. Furthermore, the results of complications in patients with total debranching were markedly worse than those in other groups. Interestingly, failure in the total debranching group developed later than the other groups (average, 55 months vs 29 months), although patients with total debranching had a tendency to experience emergency situations or poor conditions. Therefore, many patients with total debranching died from inoperable conditions. In general, the results of elective open conversion were acceptable. However, patients undergoing emergency surgery or conservative care did not survive. Thus, this study suggests that, when performed in a timely manner, open conversion is important for rescuing patients. Furthermore, repeated reintervention or conservative care should be avoided.

CONCLUSIONS

Late complications after hybrid arch repair occurred in a substantial proportion of patients. Regardless of zone type, the incidence of late complications was relatively high. Timely reintervention and open conversion were important for survival, but repeated reintervention or conservative care would not be recommended. Importantly, aggressive management and life-long surveillance after hybrid arch repair are mandatory for better outcomes.

AUTHOR CONTRIBUTIONS

Conception and design: HJ, YY, KY
Analysis and interpretation: HJ, YY, JK, DL, YK, KY
Data collection: HJ, YY, JK, JW, DL, YK, DC
Writing the article: HJ, YY, JK, KY
Critical revision of the article: HJ, YY, JK, JW, DL, YK, DC, KY
Final approval of the article: HJ, YY, JK, JW, DL, YK, DC, KY
Statistical analysis: HJ, YY
Obtained funding: Not applicable
Overall responsibility: HJ

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Supplementary Table I (online only). Multivariate analysis of composite of perioperative mortality and major morbidity

Variables	HR	95% CI	*P* value
Age	1.130	1.002-1.301	.039
CKD	6.764	1.405-32.564	.017
Type of debranching (zone 0 vs others)	4.680	1.012-21.680	.048

CI, Confidence interval; *CKD,* chronic kidney disease; *HR,* hazard ratio.

Supplementary Table II (online only). Comparison of late complications according to the one or two stage procedures

Variables	One stage (n = 10)	Two stage (n = 55)	*P* value
Late aorta-related mortality	2 (20)	8 (15)	.66
Late complications	4 (40)	21 (38)	.91

Values are presented as number (%).

Supplementary Table III (online only). Comparison of late complications according to the stent graft type

Variables	Valiant (n = 31)	Seal (n = 20)	Cook TX2 (n = 14)	*P* value
Late aorta-related mortality	5 (16)	3 (15)	2 (14)	.99
Late complications	12 (39)	8 (40)	5 (38)	.97
Type I endoleak	3	3	2	–
RTAD	1	1	–	–
SINE	2	1	–	–
Stent fracture	–	1	–	–
Stent migration	1	1	1	–

RTAD, Retrograde type A dissection; *SINE,* distal stent graft-induced new entry.
Values are presented as number (%) or number.