Long-term outcomes of primary surgical repair for communicating DeBakey IIIb chronic dissecting aortic aneurysm

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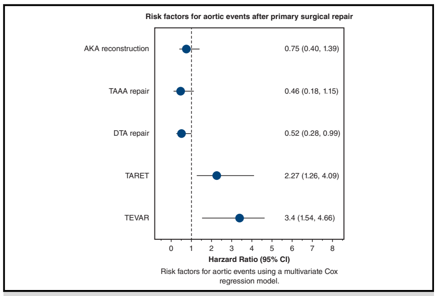
ABSTRACT

Objective: This study aimed to evaluate the long-term outcomes of surgical strategies for communicating DeBakey IIIb chronic dissecting aortic aneurysm, considering the optimal primary surgical repair to prevent aortic events.

Methods: From 2002 to 2021, 101 patients with communicating DeBakey IIIb chronic dissecting aortic aneurysm who underwent surgical repair were categorized based on the primary surgical repair: 1-stage repair of thoracoabdominal aortic aneurysm (TAAAR) ($n = 22$) or staged repair, such as descending thoracic aneurysm repair (DTAR) ($n = 43$) or total arch replacement with elephant trunk implantation (TARET) ($n = 25$), and thoracic endovascular aortic repair (TEVAR) ($n = 11$). Early and late postoperative outcomes were compared among the groups.

Results: Early outcomes for TAAAR, DTAR, TARET, and TEVAR were associated with the incidence of stroke (9.1% vs 0% vs 4.0% vs 9.1%, respectively), spinal cord injury (13.6% vs 4.7% vs 8.0% vs 0%, respectively), and in-hospital mortality (9.1% vs 2.3% vs 0% vs 9.1%, respectively). During follow-up, the 10-year overall survival and 7-year aortic event-free rates for TAAAR, DTAR, TARET, and TEVAR were 61.8%, 71.6%, 21.5%, and 26.5% and 93.8%, 84.3%, 74.4%, and 51.4%, respectively. TAAAR had significantly higher overall survival ($P = .05$) and aortic event-free rates ($P = .03$) than TEVAR. TARET (hazard ratio, 2.27; $P < .01$) and TEVAR (hazard ratio, 3.40; $P < .01$) were independently associated with the incidence of aortic events during follow-up.

Conclusions: Considering the optimal primary surgical repair based on long-term outcomes, TEVAR was not a durable treatment option. Patient-specific TAAAR or DTAR should be considered rather than defaulting to minimally invasive primary repairs for all patients with communicating DeBakey IIIb chronic dissecting aortic aneurysm. (JTCVS Open 2024;20:1-13)



Risk factors for late aortic events using a multivariate Cox regression model.

CENTRAL MESSAGE

Primary surgical repair by total arch replacement with elephant trunk implantation or thoracic endovascular aortic repair is a risk factor for late aortic events during follow-up.

PERSPECTIVE

Optimal choice of primary treatment for communicating DeBakey IIIb chronic dissecting aortic aneurysm remains controversial. Evidence from this study indicates that TARET and TEVAR are independently associated with the incidence of late aortic events during follow-up. This result should be considered when choosing the optimal primary surgical repair to prevent the incidence of aortic events.

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IRB approval: Data collection, analysis, and reporting for this study were approved by the Sapporo Medical University's Institutional Review Board (reference No.: 352-78; current approval date: July 29, 2023).

Informed consent statement: All patients enrolled in the study provided written informed consent for release of information.

Read at The American Association for Thoracic Surgery Aortic Symposium 2024, New York, New York, April 25-26, 2024.

Received for publication March 4, 2024; revisions received May 6, 2024; accepted for publication May 19, 2024; available ahead of print June 18, 2024.

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2666-2736

https://doi.org/10.1016/j.xjon.2024.05.009

Abbreviations and Acronyms

AKA	= artery of Adamkiewicz
CD3bDA	= communicating DeBakey IIIb chronic dissecting aortic aneurysm
CPB	= cardiopulmonary bypass
CSF	= cerebrospinal fluid
CT	= computed tomography
d-SINE	= distal stent graft-induced new entries
DTAR	= descending thoracic aneurysm repair
ET	= elephant trunk
FL	= false lumen
MFS	= Marfan syndrome
SCI	= spinal cord injury
TAAAR	= thoracoabdominal aortic aneurysm repair
TAR	= total arch replacement
TARET	= total arch replacement with elephant trunk implantation
TEVAR	= thoracic endovascular aortic repair
TL	= true lumen

Chronic type B aortic dissection and previous aortic repair of type A aortic dissection cause extensive aortic aneurysms in the chronic phase.[1,2] Communicating DeBakey IIIb chronic dissecting aortic aneurysm (CD3bDA), which presents dissection extending to the visceral artery due to the existing pressurized false lumen (FL) through the distal entries, can dilate more easily than thrombosed FL dissecting aortic aneurysms. The risk of CD3bDA rupture increases with diameters >50 mm,[3,4] and requires surgical interventions such as open repair or thoracic endovascular aortic repair (TEVAR). Open repair for dissecting aortic aneurysm of descending thoracic or thoracoabdominal lesions has traditionally been used to treat this pathology and is associated with a high mortality (8% to 9.6%).[5-8] Although a variety of surgical techniques have been used and technology has progressed, these procedures remain among the most significantly invasive surgeries.

In recent years, the enthusiasm for TEVAR for chronic aortic dissection has grown because it offers a less invasive alternative to open repair and decreased morbidity and mortality. However, less encouraging midterm results after TEVAR for chronic aortic dissection have been published, with some studies reporting failure of the procedure in 37% of patients within 36 months due to endoleak, development of an aneurysm of the distal aorta, or continued FL perfusion with aneurysmal dilatation.[9] Therefore, the current preference for TEVAR in managing CD3bDA has been questioned.

Staged aortic repair with total arch replacement (TAR) is an attractive option for reducing surgical invasiveness. This procedure involves placing a prosthetic vascular graft, the elephant trunk (ET), in the dissected descending thoracic aorta. The benefits of ET implantation include reduction of the risk of aorta-related complications by avoiding open proximal anastomosis and being potentially used as a proximal landing during TEVAR. Although this conditioning can provide various secondary surgical options in staged aortic repair for CD3bDA, the surgical intervention for patients with a healthy ascending aorta and aortic arch remains controversial.

This study aimed to evaluate the 20-year long-term surgical outcomes for CD3bDA at our institution and to determine the optimal primary treatment option to prevent the incidence of aortic events during follow-up.

MATERIALS AND METHODS

Between October 2002 and June 2021, 101 patients underwent surgical repair for CD3bDA. Primary surgical repairs were electively performed when the thoracic component of the aneurysm was >50 mm in patients with connective tissue disorders or >55 mm in patients without connective tissue disorders or represented a rapid growth rate >5 mm in 6 months based on computed tomography (CT) images. The patients were categorized into 4 groups based on the primary surgical repair: 1-stage repair of thoracoabdominal aortic aneurysm (TAAAR) (n = 22) or staged repair, such as descending thoracic aneurysm repair (DTAR) (n = 43) or TAR with ET implantation (TARET) (n = 25), and TEVAR (n = 11) (Figure 1). The staged repairs included additional aortic surgeries for downstream dilatation of the distal dissecting aorta. Patients with emergency repair, aortic rupture or malperfusion, aorto-bronchial or aorto-esophageal fistulas, or previous aortic repair of type A aortic dissection or abdominal aortic aneurysm were excluded from this study.

Postoperative complications included a permanent stroke (defined as a new-onset neurological deficit and/or evident brain injury visualized on postoperative CT or magnetic resonance imaging that was accompanied by permanent damage to brain tissue) and spinal cord injury (SCI) (defined as motor and/or sensory deficits presenting with permanent paraplegia). The patients were followed up at our institution and the outpatient clinic, and follow-up CT was usually performed 6 to 12 months after hospital discharge and annually thereafter. Follow-up information on survival, general health status, and causes of late mortality was obtained from the data at the outpatient clinic through written or telephone contact with patients or relatives.

Aorta-related reintervention was defined as any unplanned re-endovascular treatment or open surgery >30 days after primary surgical repair for dilatation or rupture of the downstream aorta including the FL, or anastomotic pseudoaneurysm, and distal stent graft induced new entries (d-SINE) during follow-up (not including planned staged repair for remaining distal dissecting aneurysms).

Additionally, an aortic event was defined as an aorta-related death, complication, and aorta-related reinterventions during the follow-up period. The study protocol was reviewed and approved by the Sapporo Medical University's Institutional Review Board (reference No.: 352-78, current approval date: July 29, 2023). All patients enrolled in this study provided written informed consent for release of information.

Operative Techniques

TAAAR and DTAR. Thoracotomy was performed following a left posterolateral incision with the crossing of the costal arch. If necessary, the abdominal aorta was exposed through a retroperitoneal approach with a diaphragmatic circumferential incision. Cardiopulmonary bypass

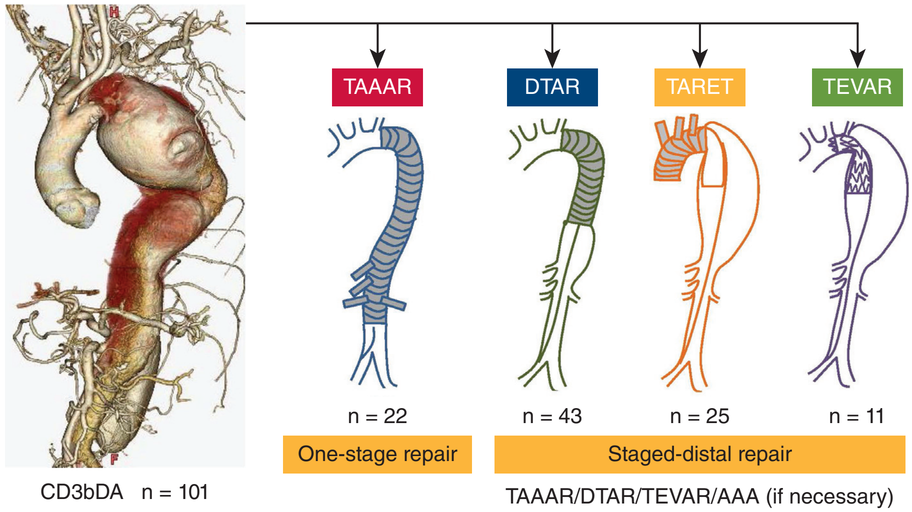


FIGURE 1. Treatment options for primary surgical repair for communicating DeBakey IIIb chronic dissecting aortic aneurysm (*CD3bDA*). CD3bDA patients were categorized into 4 groups according to the primary surgical repair: 1-stage thoracoabdominal aortic aneurysm repair (*TAAAR*) or staged repair such as descending thoracic aneurysm repair (*DTAR*) or preemptive total arch replacement with elephant trunk implantation (*TARET*) and thoracic endovascular aortic repair (*TEVAR*).

(CPB) was established using the right axillary and right femoral arteries for arterial inflow and the right femoral vein and pulmonary artery for venous drainage. Proximal anastomosis near the left subclavian artery was performed using aortic crossclamping or the open proximal method under circulatory arrest. The target temperature was set at 25 °C (moderate hypothermia) for spinal cord protection when proximal aortic clamping was considered to be performed safely, whereas open proximal anastomosis was applied under deep hypothermia (18-20 °C) when the patient was at a high risk of SCI due to extensive graft replacement. Identification of the artery of Adamkiewicz (AKA) was made preoperatively using CT or magnetic resonance imaging. If the identified AKA was within the replacement range, a target intercostal artery was reconstructed as a donor artery to the AKA. Visceral arteries were preserved using a beveled technique or reconstructed using quadrifurcated graft. Although transcranial motor-evoked potentials were intraoperatively monitored to identify spinal cord ischemia, preoperative cerebrospinal fluid (CSF) drainage tube insertion was not routinely performed.

TARET. All operative maneuvers were performed through a median sternotomy. CPB was established with ascending aortic cannulation, although arterial perfusion was applied through the graft anastomosed to the right axillary artery, depending on the patient's aortic condition. Selective antegrade cerebral perfusion was used for brain protection under moderate hypothermic circulatory arrest. Stepwise distal anastomoses were performed using a quadrifurcated arch graft. An invaginated tube graft was inserted into the narrowed true lumen (TL) of the descending aorta or deployed into the entire lumen to ensure blood flow into the FL if the AKA, or visceral arteries, mainly originated from the FL. The length of the ET graft was determined based on the intraoperative findings to cover the primary entry tear and was set at 7 cm in most cases. After distal anastomosis, the left subclavian artery was reconstructed and the patient was subsequently rewarmed. The proximal aorta was repaired using direct graft anastomosis, and the other 2 arch vessels were reconstructed using branch grafts. This study only included patients in whom the conventional ET technique was used and did not include patients in whom the frozen ET technique was used.

TEVAR. All endovascular procedures were performed in the operating room under general anesthesia. CSF drainage was not routinely performed. Individual surgeons used anatomically suitable commercial devices according to the manufacturer's instructions for the TAG (W.L. Gore & Associates Inc), Zenith TX2 (Cook Medical LLC), and Valiant Captiva (Medtronic). The graft size was 10% to 15% larger than the diameter of the proximal nondissecting aorta. Distal graft oversizing was measured relative to the narrow TL diameter of the dissected descending aorta. For zone 1 or 2 proximal landing, a debranching bypass or stent-graft fenestration was performed. Intravascular ultrasonography confirmed the guidewire passage through the TL. In most patients, the stent graft was deployed up to the TL above the celiac artery to cover the primary entry even when the FL was patent in the abdominal aorta. Simultaneous intervention in the FL was not routinely performed during the primary TEVAR.

Statistical Analyses

Continuous data are presented as mean ± SD. Categorical data are presented as proportions and were compared between subgroups using Fisher exact test. One-way analysis of variance was used to compare continuous data, and χ^2 tests were used to compare categorical data for more than 2 groups. If there was a statistically significant difference among the 4 groups, further analysis was performed using the Tukey-Kramer test or Dunnett test to identify which groups had significant differences. Risk factors were identified using logistic regression analysis for in-hospital mortality and SCI or Cox regression analysis for aortic events. Nonparametric estimates of freedom from all-cause mortality, aortic events, and reintervention after primary surgical repair were determined using the Kaplan-Meier method. Data were analyzed using JMP Pro 17 (SAS Institute Inc).

RESULTS

Between 2002 and 2021, 101 patients (84 men; mean age, 59.4 years) underwent surgical repair for CD3bDA. Of the enrolled patients, 22 (21.8%), 43 (42.6%), 25 (24.7%), and 11 (10.9%) underwent TAAAR, DTAR, TARET, and TEVAR, respectively. The characteristics of the enrolled patients are shown in Table 1. There were no significant differences in all variables among patients who underwent

TABLE 1. Baseline characteristics of the patients

Variable	Total (n = 101)	TAAAR (n = 22)	DTAR (n = 43)	TARET (n = 25)	TEVAR (n = 11)	*P* value
Age (y)	59.4 ± 13.7	55.1 ± 15.5	58.1 ± 12.9	62.8 ± 13.4	65.6 ± 10.9	.092
Male sex	84 (83.2)	19 (86.4)	34 (79.1)	22 (88.0)	9 (81.8)	.775
Marfan syndrome	19 (18.8)	8 (36.4)	8 (18.6)	3 (12.0)	0 (0)	.027
Hypertension	79 (78.2)	17 (77.3)	35 (81.4)	16 (64.0)	11 (100.0)	.098
Diabetes mellitus	8 (7.9)	3 (13.6)	5 (11.6)	0 (0)	0 (0)	.180
Dyslipidemia	17 (16.8)	3 (13.6)	6 (13.9)	7 (28.0)	1 (9.1)	.375
Smoking*	63 (62.4)	13 (59.1)	27 (62.8)	17 (68.0)	6 (54.6)	.866
CKD†	9 (8.9)	2 (9.1)	3 (7.0)	2 (8.0)	2 (18.2)	.708
LVEF (%)	62.3 ± 3.7	63.0 ± 2.1	60.8 ± 2.9	61.3 ± 3.1	59.9 ± 2.6	.331
COPD	39 (38.6)	7 (31.8)	15 (34.9)	13 (52.0)	4 (36.4)	.459
Aneurysm diameter (mm)	58.5 ± 10.6	60.2 ± 11.5	58.6 ± 10.8	59.3 ± 8.4	56.6 ± 11.7	.255
Interval from onset (mo)	64.3 ± 10.6	54.7 ± 25.4	77.9 ± 18.2	48.8 ± 26.1	60.2 ± 34.0	.785
SVS/STS classification (zone)						
Extent of proximal dissection	3.0 ± 0.9	3.6 ± 0.9	3.1 ± 0.7	2.4 ± 1.0	3.0 ± 0.2	<.0001
Extent of distal dissection	9.4 ± 1.4	8.9 ± 1.5	9.6 ± 1.3	9.4 ± 1.3	9.5 ± 1.2	.267

Values are presented as mean ± SD or n (%). *TAAAR*, Thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair; *CKD*, chronic kidney disease; *LVEF*, left ventricle ejection fraction; *COPD*, chronic obstructive pulmonary disease; *SVS/STS*, Society for Vascular Surgery/Society of Thoracic Surgeons. *Includes current and past smokers. †Creatinine >1.5 mg/dL.

TAAAR, DTAR, TARET, or TEVAR, except the diagnosis of Marfan syndrome (MFS) (36.4% vs 18.6% vs 12.0% vs 0%, respectively), and proximal dissection extent as defined by the Society for Vascular Surgery/Society of Thoracic Surgeons classification (zone 3.6 ± 0.9 vs 3.1 ± 0.7 vs 2.4 ± 1.0 vs 3.0 ± 0.2, respectively). Patients who underwent TAAAR had a significantly higher rate of MFS compared with those who underwent TEVAR ($P = .016$). Additionally, the proximal extent of dissection in TARET was significantly more proximal than that in TAAAR ($P < .001$) or DTAR ($P = .004$).

In TAAAR, the extent of graft replacement was Crawford I (13.6%) and II (86.4%). Proximal anastomosis was performed using the open proximal method (54.5%) or aortic crossclamping (45.5%). In the DTAR, proximal anastomosis was performed using the open proximal method (69.8%) or aortic crossclamping (30.2%), whereas distal anastomosis was performed using the fenestration anastomosis technique (83.7%) or FL closure method (16.3%). In TARET, the distal edge of the inserted ET was located in the TL of the descending aorta (84.0%) or the entire lumen (16.0%). For TEVAR, the proximal landing was at zones 1 (27.3%), 2 (27.3%), and 3 (45.4%), and the median distal landing was at Th11 (Th8-12). Zone 1 or 2 landing TEVAR was performed using a debranching bypass (n = 2) or fenestration technique (n = 4).

Table 2 shows the intraoperative data and postoperative outcomes. Among the 4 groups, there were significant differences in the following variables: operation time, CPB time, moderate hypothermia, preoperative insertion of CSF drainage, AKA reconstruction, usage of blood products, and prolonged ventilation (>24 h) postoperatively. The operation time in the TEVAR was significantly shorter than that in the other surgical repairs ($P < .0001$), and the CPB time in TAAAR was significantly longer than those in the DTAR ($P < .0001$) and TARET ($P = .0003$). Additionally, TAAAR used significantly more blood products than the other 3 repairs ($P < .0001$) and had a significant difference in prolonged ventilation compared with TARET ($P = .05$) and TEVAR ($P = .01$). Regarding SCI prevention, the rates of preoperative insertion of CSF drainage and AKA reconstruction in TAAAR were the highest among the other repairs.

The in-hospital mortality rates for TAAAR, DTAR, TARET, and TEVAR were 9.1%, 2.3%, 0%, and 9.1%, respectively. The incidence rates of permanent stroke and SCI were 9.1%, 0%, 4.0%, and 9.1%, and 13.6%, 4.7%, 8.0%, and 0% in TAAAR, DTAR, TARET, and TEVAR, respectively. However, no significant differences were observed among the 4 groups.

The 4 in-hospital deaths were due to a fatal arrhythmia, graft infection associated with esophageal perforation after TAAAR, severe pulmonary bleeding after DTAR, and extensive stroke after zone 1 landing TEVAR with 2-debranching bypass.

Four patients had permanent strokes: 2 patients who underwent TAAAR using the open proximal anastomosis technique; 1 patient who underwent TARET, developed

TABLE 2. Intraoperative data and early outcomes by primary surgical repair

Variable	Total (n = 101)	TAAAR (n = 22)	DTAR (n = 43)	TARET (n = 25)	TEVAR (n = 11)	*P* value
Perioperative data						
Operation time (min)	527.2 ± 222.3	770.3 ± 165.3	541.7 ± 159.8	449.3 ± 222.3	161.5 ± 107.0	<.0001
CPB time (min)	206.7 ± 66.6	273.1 ± 59.1	169.9 ± 55.9	211.3 ± 37.9	NA	<.0001
Lowest temperature (°C)	25.5 ± 6.7	26.9 ± 7.7	25.7 ± 7.6	23.9 ± 2.5	NA	.297
Deep hypothermia	21 (23.3)	6 (27.3)	13 (30.2)	2 (8.0)	NA	.100
Moderate hypothermia	41 (45.6)	6 (27.3)	13 (30.2)	22 (88.0)	NA	<.0001
Preoperative CSF drainage	37 (36.6)	13 (59.1)	22 (51.2)	0 (0)	1 (9.1)	<.0001
AKA reconstruction	31 (34.4)	15 (68.2)	15 (34.9)	0 (0)	NA	< 0001
Red blood cells (U)	18.9 ± 15.0	33.7 ± 13.5	19.1 ± 14.0	12.3 ± 5.9	2.5 ± 1.3	<.0001
Fresh frozen plasma (U)	14.6 ± 10.6	25.2 ± 12.4	14.8 ± 6.2	10.4 ± 6.6	1.1 ± 0.3	<.0001
Platelet (unit)	18.2 ± 10.2	23.9 ± 11.6	19.9 ± 7.1	17.9 ± 6.9	1.4 ± 0.4	<.0001
Postoperative data						
Prolonged ventilation (>24 h)	32 (31.7)	12 (54.6)	14 (32.6)	5 (20.0)	1 (9.1)	.023
Stroke, permanent	4 (3.9)	2 (9.1)	0 (0)	1 (4.0)	1 (9.1)	.255
Spinal cord injury	8 (7.9)	3 (13.6)	2 (4.7)	2 (8.0)	0 (0)	.433
In-hospital mortality	4 (3.9)	2 (9.1)	1 (2.3)	0 (0)	1 (9.1)	.306
Staged-distal repair	36 (35.6)	0 (0)	15 (34.9)	19 (76.0)	2 (18.2)	<.0001
Aorta-related reintervention	15 (14.9)	1 (4.5)	6 (13.9)	3 (12.0)	5 (45.5)	.017

Values are presented as mean ± SD or n (%). *TAAAR*, Thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair; *CPB*, cardiopulmonary bypass; *NA*, not available; *CSF*, cerebrospinal fluid; *AKA*, artery of Adamkiewicz.

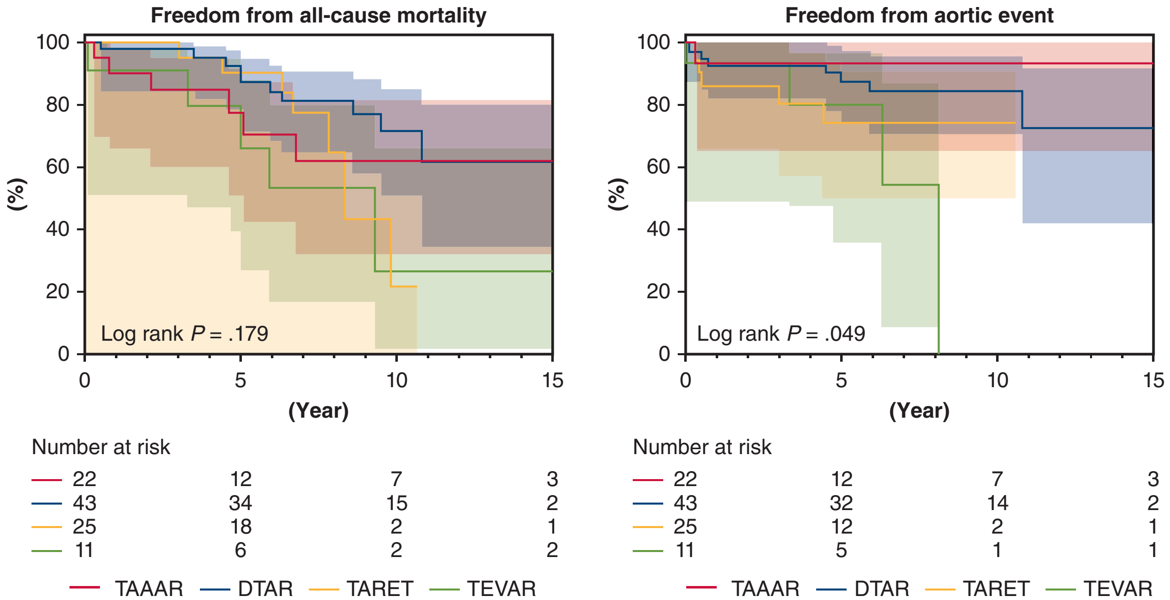
persistently impaired consciousness, and required a tracheostomy; and 1 patient who underwent TEVAR, developed a massive cerebral infarction, and died in the hospital.

Eight patients sustained SCI after the primary repair: 3 patients with TAAAR underwent graft replacement with Crawford extent II, of whom the segmental artery leading to AKA was not reconstructed because it was not preoperatively identified due to the presence of a near 100% occlusion of the intercostal artery based on the significant shaggy aorta. Two patients with DTAR developed SCI despite AKA reconstruction; 1 of these 2 patients had decreased transcranial motor-evoked potentials after AKA reconstruction. However, CSF drainage was not preoperatively performed because of the risk of hemorrhagic complications. Of the 2 patients who underwent TARET, 1 patient developed hemodynamic instability due to postoperative cardiac tamponade. The other patient was considered to have an incidental AKA embolization; however, the cause was unclear based on imaging investigations.

Figure 2 shows the long-term outcomes based on primary surgical repair. The 10-year overall survival and 7-year aortic event-free rates for TAAAR, DTAR, TARET, and TEVAR were 61.8%, 71.6%, 21.5%, and 26.5 and 93.8%, 84.3%, 74.4%, and 51.4%, respectively. TAAAR had significantly higher overall survival ($P = .048$) and aortic event-free rates ($P = .048$) than TEVAR. Twenty-six late deaths occurred during the follow-up period. The rates of major cardiovascular deaths, including aortic-, cardiac-, and cerebral-related deaths, were 33.3%, 55.6%, 71.4%, and 50.0% for TAAAR, DTAR, TARE, and TEVAR, respectively (Table E1). A subgroup analysis showed the comparison of late outcomes based on patients with MFS (Figure E1). In patients with MFS, the 10-year overall survival for both TAAAR and DTAR was as high as 100%, whereas in non-MFS patients, the rate was 43.8% for TAAAR and 64.3% for DTAR. However, these differences were not significant.

The staged distal repair rates of the residual dissecting aorta for TAAAR, DTAR, TARET, and TEVAR were 0%, 34.9%, 76.0%, and 18.2%, respectively (Table 2). The rate in TARET was significantly higher than that in other surgical repairs ($P < .0001$). Two patients who underwent DTAR were unable to proceed to the second stage of open repair due to postoperative death (n = 1) and SCI (n = 1), respectively.

For TARET, staged distal repair was performed using TAAAR (n = 4), DTAR (n = 5), and TEVAR (n = 10). In contrast, 6 patients had complete FL thrombosis by primary entry closure with ET implantation. Secondary TEVAR was selected in patients with SCI, with ruptured FL due to rapid dilatation, or in those who were considered unable to tolerate left thoracotomy after primary TARET. Six of the 10 patients treated with secondary TEVAR required reintervention because of d-SINE or FL dilatation caused by reperfusion from uncovered re-entries. This situation reflected a lower aorta-related reintervention freedom rate of 10-years for TEVAR (33.3%) compared with 66.7% for TAAAR and DTAR (Figure 3).



	5 year	10 year	15 year
TAAAR	77.6%	61.8%	61.8%
DTAR	86.9%	71.6%	61.4%
TARET	90.2%	21.5%	NA
TEVAR	66.3%	26.5%	26.5%

	5 year	7 year	10 year
TAAAR	93.8%	93.8%	93.8%
DTAR	87.2%	84.3%	84.3%
TARET	74.4%	74.4%	74.4%
TEVAR	77.1%	51.4%	NA

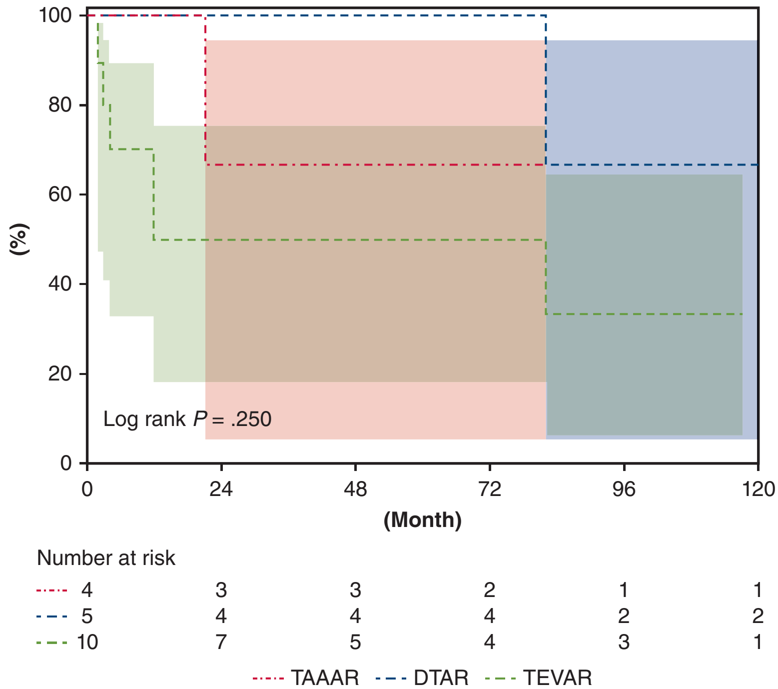
FIGURE 2. Comparisons of late outcomes according to the primary surgical repair. The Kaplan-Meier curve with 95% confidence limit is shown. A, Freedom from all-cause mortality. B, Freedom from aortic event. Aortic event was defined as aorta-related death, complication, and reintervention and downstream aortic dilatation, dissection, or rupture during the follow-up period. *TAAAR*, Thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair.

During the follow-up period, the aorta-related reintervention rates for TAAAR, DTAR, TARET, and TEVAR were 4.5%, 13.9%, 12.0%, and 45.5%, respectively (Table 2). The rate in TEVAR was significantly higher than that in the other surgical repairs ($P < .0001$). Fifteen patients required aorta-related reintervention. In the group who underwent TAAAR, 1 patient was treated with additional bypass grafting of the saphenous vein for severe graft stenosis of the reconstructed left renal artery. In the DTAR group, 6 patients were treated for rapid FL dilatation or anastomosis-related pseudoaneurysms. In the TARET group, 3 patients were treated for rapid FL dilatation immediately after primary repair or d-SINE caused by secondary TEVAR. In the TEVAR group, 5 patients were treated with emergency TAR for stent-graft proximal migration and with additional TEVAR for d-SINE or FL dilatation caused by reperfusion from uncovered re-entries.

Multivariate analysis failed to identify a significant risk factor for in-hospital mortality. However, there was a statistical tendency for CPB time (hazard ratio [HR], 1.30; 95% CI, 0.99-1.06; $P = .06$) and deep hypothermia (HR, 14.49; 95% CI, 0.59-35.5; $P = .06$) to be risk factors (Table 3). Additionally, multivariate Cox regression analysis showed that TARET (HR, 2.27; 95% CI, 1.26-4.09; $P = .007$) and TEVAR (HR, 3.40; 95% CI, 1.53–4.66; $P = .003$) were independently associated with aortic events during the follow-up period (Table 4).

DISCUSSION

Chronic aortic dissection is a challenging surgical problem, and optimal treatment continues to be debated. We evaluated the long-term outcomes of primary surgical repair using TAAAR, DTAR, TARET, or TEVAR for CD3bDA. The goals for open repair of CD3bDA include resection of all aneurysmal diseases, maintenance of distal organ perfusion and major aortic branches, and elimination of the primary proximal tear. In contrast, the primary goal of TEVAR is to exclude the primary and re-entry tears to achieve thrombosis of the false channel and ultimately promote remodeling. Nienaber and colleagues[10] revealed that aortic remodeling by TEVAR for early-phase type B dissection led to the reduction of complications in the



	1 year	5 year	10 year
TAAAR	100%	66.7%	66.7%
DTAR	100%	100%	66.7%
TEVAR	50%	50.0%	33.3%

FIGURE 3. Freedom from aorta-related reintervention after primary total arch replacement with elephant trunk implantation (*TARET*). After primary TARET, staged distal repair was performed using thoracoabdominal aortic aneurysm repair (*TAAAR*) (n = 4), descending thoracic aneurysm repair (*DTAR*) (n = 5), and thoracic endovascular aortic repair (*TEVAR*) (n = 10). Six patients exhibited complete false lumen (*FL*) thrombosis by primary entry closure with ET implantation. The Kaplan-Meier curve with 95% confidence limit is shown. Aorta-related reintervention freedom rates were higher at 66.7% for TAAAR and DTAR compared with 33.3% for TEVAR.

chronic phase; those results led to the increased interest in using TEVAR for chronic aortic dissection. A large meta-analysis of the early outcomes after TEVAR revealed the rates of 30-day mortality (range, 0%-20%),[11-14] SCI (0%-2.8%), and stroke (0%-6.7%).[15] The midterm results are less encouraging, with some studies reporting failure of the procedure in 37% of patients within 36 months.[9] The reintervention rates were reported as 13% to 40%, with additional endovascular or open surgical procedures usually occurring within the first 24 months following primary TEVAR.[16-21]

Our findings also revealed that 45.5% of patients required numerous reinterventions following TEVAR, with an aortic event-free rate of 51.4% after 7 years. Additionally, TEVAR was also recognized as a predictor of increased aortic events against open repair. The difficulty with the endovascular exclusion of CD3bDA may involve a small TL with a thick and stiff intimal flap, which may be less amenable to reverse remodeling using TEVAR than an acutely dissected aorta with a more flexible intimal flap. The concern is not the exclusion of the reentry at the level of the stent graft but rather at the level distal to the stent graft where retrograde pressurization of the FL may persist. Complete FL thrombosis after TEVAR for chronic aortic dissection occurs in only 40% to 80% of patients at the level of the device and in 0% to 40% of patients at the level distal to the device.[9,13,16-18,22] Persistent FL perfusion is an independent risk factor of progressive aortic enlargement and adverse long-term outcomes.[23] These issues are likely responsible for the relatively early need for reinterventions with TEVAR in chronic dissection. This is supported by our findings that patients who underwent TEVAR had a shorter time elapse from primary surgery to staged surgery than patients who underwent DTAR (2.3 months; range, 0.4-4.2 months vs 27.2 months; range, 13.5-67.9 months [data not presented]). Therefore, simple TEVAR may not provide long-term durability for patients with extensive thoracoabdominal aortic dissection.

TABLE 3. Multivariate analyses for in-hospital mortality and spinal cord injury

Variable	Hazard ratio	95% CI	P value	Hazard ratio	95% CI	P value
In-hospital mortality						
Age	1.18	0.02-57.9	.93			
Marfan syndrome	NA	NA	NA			
EuroSCORE standard	1.13	0.79-1.74	.57			
Proximal dissection extent	1.34	0.42-4.23	.61			
CPB time (min)	1.02	1.00-1.34	.04	1.30	0.99-1.06	.06
Deep hypothermia	7.16	0.62-83.26	.10	14.49	0.59-35.5	.06
AKA reconstruction	4.00	0.35-45.96	.27			
TAAAR	3.85	0.51-29.04	.19	0.72	0.024-22.18	.85
DTAR	0.44	0.04-4.35	.48			
TARET	NA	NA	NA			
TEVAR	2.90	0.27–30.59	.38			
Spinal cord injury						
Age	1.24	0.07-21.18	.88			
Marfan syndrome	1.49	0.28-8.03	.64			
EuroSCORE standard	1.33	0.97-1.81	.08	1.37	0.96-1.97	.81
Proximal dissection extent	1.98	0.83-4.66	.12	1.72	0.79-3.74	.16
CPB time (min)	1.01	0.99-1.20	.14	1.01	0.99-1.02	.19
Deep hypothermia	NA	NA	NA			
AKA reconstruction	2.04	0.47-8.78	.34			
TAAAR	2.34	0.51-10.66	.27			
DTAR	0.42	0.08-2.21	.28			
TARET	1.93	0.43-8.76	.40			
TEVAR	NA	NA	NA			

Backward elimination with variables with $P < .2$ in the univariate analysis. *NA*, Not available; *EUROScore*, European System for Cardiac Operative Risk Evaluation; *CPB*, cardiopulmonary bypass; *AKA*, artery of Adamkiewicz; *TAAAR*, thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair.

This study revealed excellent long-term survival and aortic event-free rates after TAAAR and DTAR. The rate of freedom from aortic events for TAAAR was 93.7% at 15 years, whereas that for DTAR were 87.3%, 84.4%, and 72.3% at 5, 10, and 15 years, respectively. Previous studies reported on the operative mortality (range, 8.0%-9.6%)[5-8] and the risk of SCI (1.1%-4.8%) and stroke (1.1%-5.6%).[6,7,22] However, these series included patients with both TAAAR and DTAR, and the subgroups were not analyzed separately. According to Japanese national registry data, the in-hospital mortality rates for TAAAR and DTAR were 7.1% and 4.5%, respectively.[24] Although our early outcomes appear comparable to these national data, more favorable early outcomes are needed for these invasive aortic surgeries to become acceptable primary repair options. One major concern is the incidence of SCI after TAAAR or DTAR. In this study, the SCI rates for TAAAR and DTAR were 13.6% and 4.7%, respectively. Deep hypothermia offers advantages for spinal cord protection. In dissecting aneurysms, proximal aortic clamping is

TABLE 4. Multivariate Cox regression analyses for aortic event*

Variable	Hazard ratio	95% CI	P value	Hazard ratio	95% CI	P value
Marfan syndrome	0.72	0.40-1.31	.28			
Proximal dissection extent	0.87	0.65-1.18	.37			
Deep hypothermia	0.80	0.45-1.41	.44			
AKA reconstruction	0.59	0.35-0.98	.04	0.75	0.40-1.39	.36
TAAAR	0.62	0.34-1.14	.12	0.46	0.18-1.15	.10
DTAR	0.73	0.46-1.16	.19	0.52	0.28-0.99	.05
TARET	1.93	1.09-3.40	.02	2.27	1.26-4.09	.007
TEVAR	2.68	1.24-3.44	.01	3.40	1.53-4.66	.003

AKA, Artery of Adamkiewicz; *TAAAR*, thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair. *Aortic event was defined as aorta-related death, complication, and reintervention and downstream aortic dilatation, dissection, or rupture during the follow-up period. Backward elimination with variables with $P < .2$ in the univariate analysis.

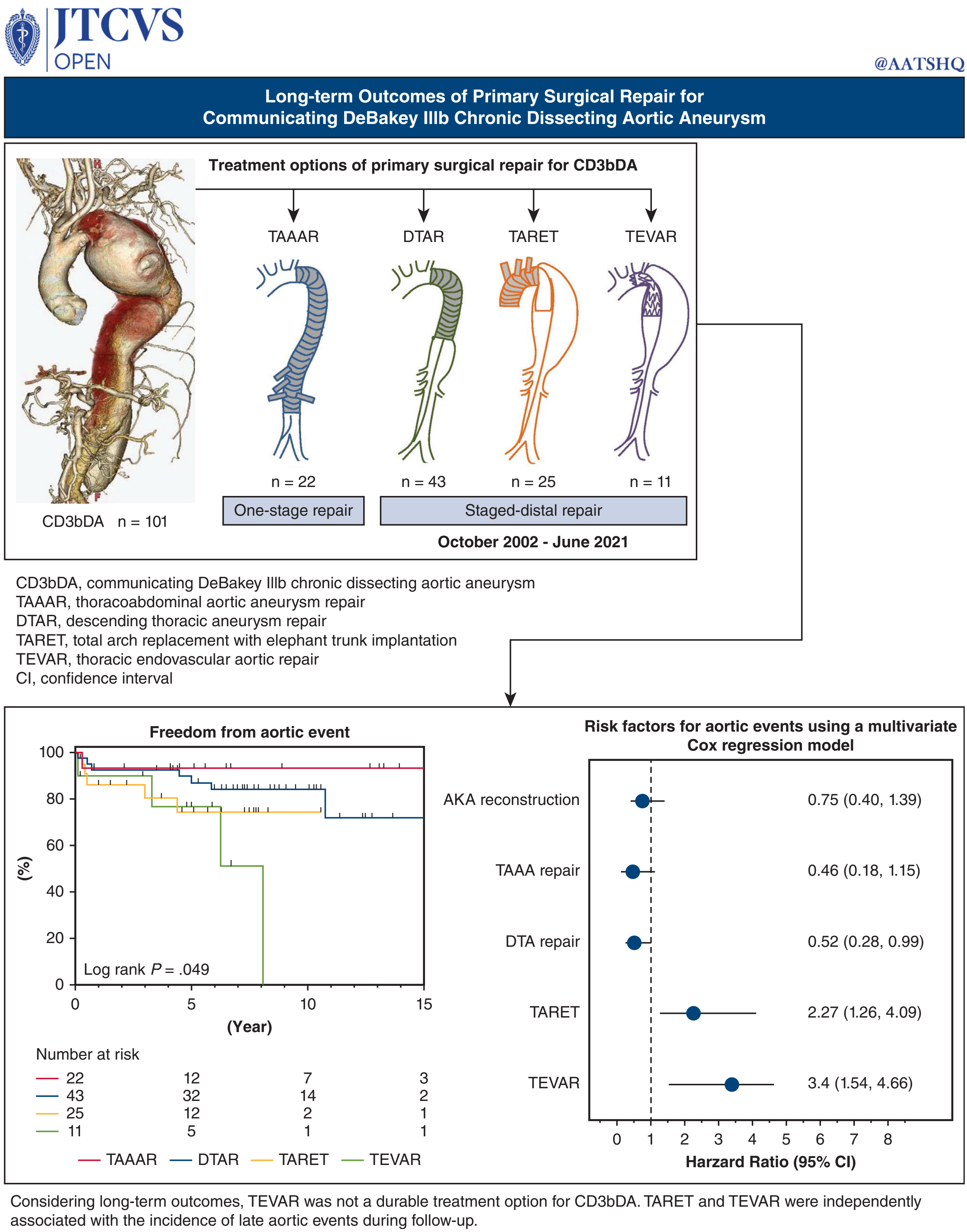


FIGURE 4. Graphical abstract. *CD3bDA*, Communicating DeBakey IIIb chronic dissecting aortic aneurysm; *TAAAR*, thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair.

sometimes difficult to perform, and the risk of aortic injury increases. Under deep hypothermic conditions, manipulation during circulatory arrest is less traumatic to the aorta. In contrast, deep hypothermia increases the risk of coagulopathy and pulmonary complications. Reflecting those facts, this study not only found that deep hypothermia tended to be a risk factor for in-hospital mortality but also that TAAAR required greater use of blood products and prolonged ventilation. Patients with MFS who underwent TAAAR or DTAR had more promising long-term outcomes than those without MFS, which was supported by the subanalysis that patients with MFS were significantly younger than those without MFS (37.9 ± 2.9 vs 64.9 ± 2.2 years [data not presented]). These results suggest that the efficacy of deep hypothermia overcomes its drawbacks when adequate patient selection is performed. Several studies have reported the importance of preoperative identification of the AKA with appropriate reconstruction or preservation[25] and reattachment of the intercostal arteries identified as the collateral network.[26] Despite these efforts, complete prevention of SCI remains difficult.

Since 2010, staged aortic repairs using TARET have been performed at our institution. This procedure focuses on inserting the ET into the dissected descending aorta. This strategy appears to be more effective in patients whose FL extends more proximally from the left subclavian artery because it can avoid aortic crossclamping or the open proximal method under deep hypothermic circulatory arrest. However, this study unexpectedly showed poor early and late outcomes. Several patients had rapidly dilated FL ruptures while awaiting secondary surgery because of changes in the FL blood flow after the ET was inserted. Although these patients were necessary candidates for secondary TEVAR, this study showed that patients treated with secondary TEVAR had a higher aorta-related reintervention rate than those who underwent secondary open repair with TAAAR or DTAR after primary TARET. To justify the strategy of staged aortic repair with TARET, early and late outcomes after TARET must improve to decrease aortic event rates. To this end, secondary aortic repair should be performed with open repair rather than TEVAR after primary TARET with faster recovery from the initial surgical invasiveness. We have employed early second-stage repair (during the same hospitalization) using minimally invasive TARET through a partial upper sternotomy in patients with CD3bDA. The ministernotomy approach improves the recovery of respiratory function with earlier postoperative extubation and reduces postoperative pain associated with a sternotomy.[27] We believe this minimally invasive TARET may allow for a smooth transition to secondary open repair through left thoracotomy in patients with CD3bDA.

This study is limited by its retrospective nature, small sample size, and single-center experience. No consistent criteria for patient selection were established. Thus, the criteria may have been determined by patient condition or surgeon subjectivity. Therefore, potential selection bias in the selection of surgical strategy could not be eliminated. As such, the findings from this study cannot be generalized to all CD3bDA patients who undergo surgery in a given institution. Additionally, our study included hemodynamically stable patients, and the outcomes for unstable patients have not been addressed by these data. Extensive patient data collection/analysis and long-term follow-up are required to further elucidate our findings.

CONCLUSIONS

Considering the optimal primary surgical repair based on long-term outcomes, our results imply that TEVAR is not the best treatment option (Figure 4). Open repair with TAAAR or DTAR for chronic dissecting aortic aneurysm can be accomplished with excellent long-term survival and aortic event-free rates, except in high-risk patients. Patient-specific TAAAR or DTAR should remain a viable primary option until the long-term efficacy of TEVAR for CD3bDA is clearly established.

Conflict of Interest Statement

The authors reported no conflicts of interest.

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

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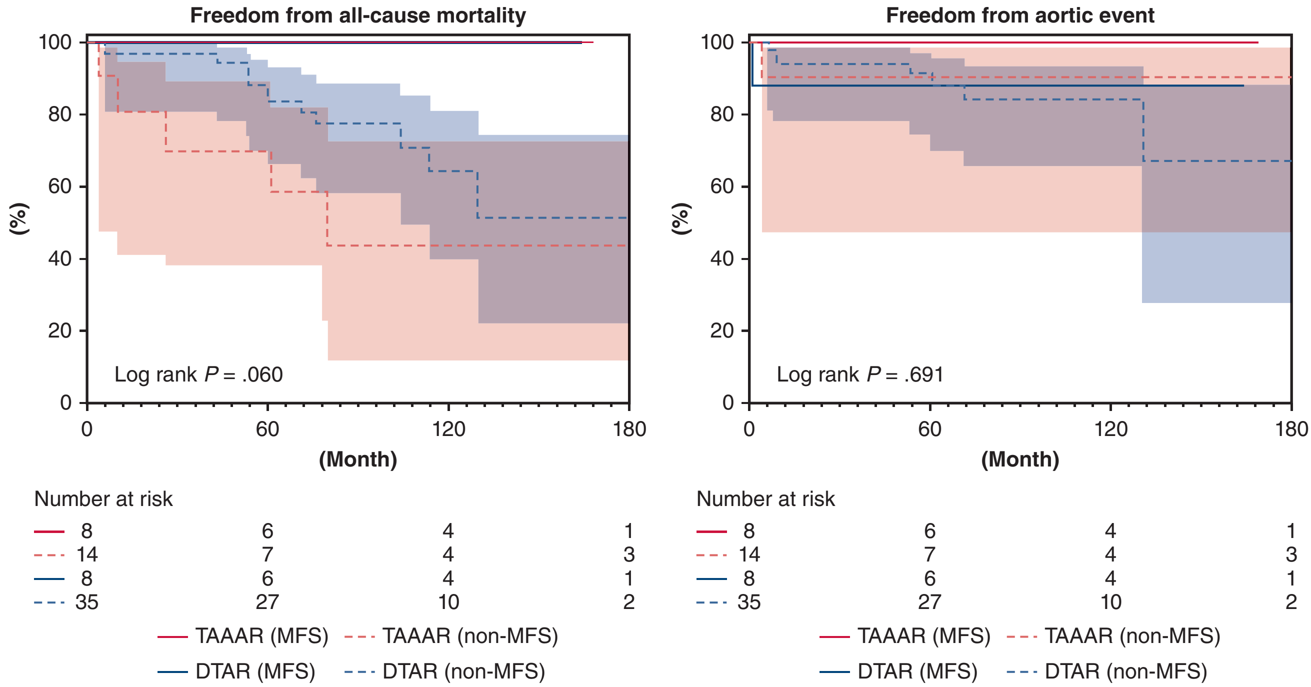
Key Words: type B aortic dissection, communicating DeBakey IIIb chronic dissecting aortic aneurysm, primary surgical repair



	5-year	10-year	15-year
TAAAR (MFS)	100%	100%	100%
TAAAR (non-MFS)	70.0%	43.8%	43.8%
DTAR (MFS)	100%	100%	100%
DTAR (non-MFS)	84.3%	64.3%	51.4%

	5-year	10-year	15-year
TAAAR (MFS)	100%	100%	100%
TAAAR (non-MFS)	90.0%	90.0%	90.0%
DTAR (MFS)	87.5%	87.5%	87.5%
DTAR (non-MFS)	87.5%	84.0%	67.2%

FIGURE E1. Comparison of late outcomes with or without Marfan syndrome (*MFS*). The Kaplan-Meier curve with 95% confidence limit is shown. A, Freedom from all-cause mortality. B, Freedom from aortic event. Aortic event was defined as aorta-related death, complication, and reintervention and significant aortic dilatation, dissection, or rupture during the follow-up period. *TAAAR*, Thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair.

TABLE E1. Cause of late mortality

Cause of late mortality	Total (n = 26)	TAAAR (n = 6)	DTAR (n = 9)	TARET (n = 7)	TEVAR (n = 4)
Aortic-related	5 (19.2)	0 (0)	3 (33.3)	2 (28.5)	0 (0)
Cardiac-related	4 (15.3)	0 (0)	1 (11.1)	3 (42.9)	0 (0)
Cerebral-related	5 (19.2)	2 (33.3)	1 (11.1)	0 (0)	2 (50.0)
Pulmonary-related	4 (15.3)	2 (33.3)	0 (0)	1 (14.3)	1 (25.0)
Malignant	5 (19.2)	1 (16.6)	3 (33.3)	1 (14.3)	0 (0)
Others	1 (3.8)	0 (0)	0 (0)	0 (0)	1 (25.0)
Senile decay	2 (7.7)	1 (16.6)	1 (11.1)	0 (0)	0 (0)

Values are presented as n (%). *TAAAR*, Thoracoabdominal aortic aneurysm repair; *DTAR*, descending thoracic aneurysm repair; *TARET*, total arch replacement with elephant trunk implantation; *TEVAR*, thoracic endovascular aortic repair.