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Original Paper

Early outcomes of thoracic endovascular aortic repair in treating type B aortic dissection

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Abstract

We evaluated the treatment results and aortic remodeling of Stanford type B aortic dissection (TBAD) following thoracic endovascular aortic repair (TEVAR) to determine the optimal timing to operate. Based on the duration from the onset of TBAD to surgery, 17 patients who underwent TEVAR for TBAD were divided into early (n = 10, TEVAR < 3 months from onset) and late (n = 7, TEVAR ≥ 3 months from onset) groups. True- and false-lumen areas were measured at four levels (A-D) using contrast-enhanced computed tomography before and after TEVAR: A, immediately after the left subclavian artery branching; B, descending aorta at the tracheal bifurcation; C, aortic annulus; and D, diaphragm. The durations from the onset of TBAD to TEVAR were 46 ± 25 days and 7.0 ± 5.3 years in the early and late groups, respectively. No major intraoperative complications were observed in either group. However, the early group had one case of retrograde type A aortic dissection 54 days after TEVAR. In the early group, true-lumen area increased at all levels, except at level A, whereas false-lumen areas decreased at all levels ($p < 0.05$). The late group showed no tendencies, except for an increased true-lumen area at level B. A difference in early aortic remodeling was observed—true-lumen area enlargement and false-lumen area decrease were more marked in the early group than the late group. TEVAR is useful when performed early after TBAD onset (within 3 months) and results in good aortic remodeling. In the late phase, the effect might be relatively smaller.

Key words: TEVAR, Stanford type B aortic dissection (DeBakey IIIb), early operation

Introduction

Conservative treatment is often selected to address acute type B aortic dissection (TBAD) unless there are serious complications such as rupture or organ ischemia. However, in ~40% of TBAD cases, dissecting aortic aneurysms occur in the long term, making treatment difficult[1,2]. While false-lumen perfusion is considered a precursor to adverse consequences, complete thrombosis can lead to aortic remodeling and improve long-term prognosis. Early intervention in uncomplicated TBAD can lead to aortic remodeling by early-entry closure via thoracic endovascular aortic repair (TEVAR)[3-5]. However, there is a risk of complications such as retrograde type A aortic dissection (RTAD) and stent graft-induced new entry (SINE), and we considered that performing TEVAR only in high-risk cases that develop dissecting aneurysms during the long-term follow-up is better[6]. In contrast, a study reported that aortic remodeling was obtained even if TEVAR was performed in the chronic phase[7]. With these findings, the optimal timing for TEVAR remains unclear. Therefore, we studied the therapeutic results and aortic remodeling to determine the optimal timing of TEVAR for TBAD.

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Materials and methods

Patients and clinical characteristics

We examined 40 patients who underwent TEVAR for TBAD between April 2014 and October 2019. Among them, five had DeBakey IIIa aortic dissection, 34 had DeBakey IIIb aortic dissection, and one had rupture. Of the 34 patients with DeBakey IIIb aortic dissection, six had the ulcer-like projection type, nine had the thrombosed type, 17 had the patent false-lumen type, and two could not be analyzed. The 17 patients with the DeBakey IIIb false-lumen type were divided into early group (n = 10) in whom TEVAR was performed 46.3 days ± 25.3 days after the onset of TBAD and late group (n = 7) in whom TEVAR was performed 7.0 ± 5.3 years (range, 2–16 years) after the onset of TBAD.

Adaption and procedures of TEVAR

Conservative treatment of uncomplicated TBAD for 22 days was our first choice according to the guidelines[8]. Afterward, if the aortic diameter at TBAD onset had been > 40 mm or follow-up computed tomography (CT) showed a rapid expansion of the aortic diameter, TEVAR was performed. TEVAR is indicated for patients with an aortic diameter of ≥ 55 mm and those whose aortic diameter expanded ≥ 5 mm within 6 months, which indicates chronic TBAD[8].

We have a policy for addressing the proximal landing zone that has not been affected by the dissected aorta—debranching was added, as necessary. Moreover, in cases of aortic dissection, we did not perform balloon crimping including in the chronic phase even if intraoperative endoleaks were observed because there was a risk of aortic rupture. The stent was long enough only to reach the major entry and to close off as much as possible the clear flow into the false lumen of the descending thoracic aorta. However, to prevent paraplegia, we avoided placing the stent farther than the level of the aortic annulus. When selecting the device, we ensured that the diameter used on the proximal side was 10% larger than the native diameter. On the distal side, we traced the circumference of the true lumen from which we calculated the diameter of the true lumen. Next, we selected a stent that was 10% larger than the diameter of the true lumen. We chose the TAG Conformable Thoracic Stent (C-TAG) (W.L. Gore & Associates, Inc., Flagstaff, AZ, USA) with an active

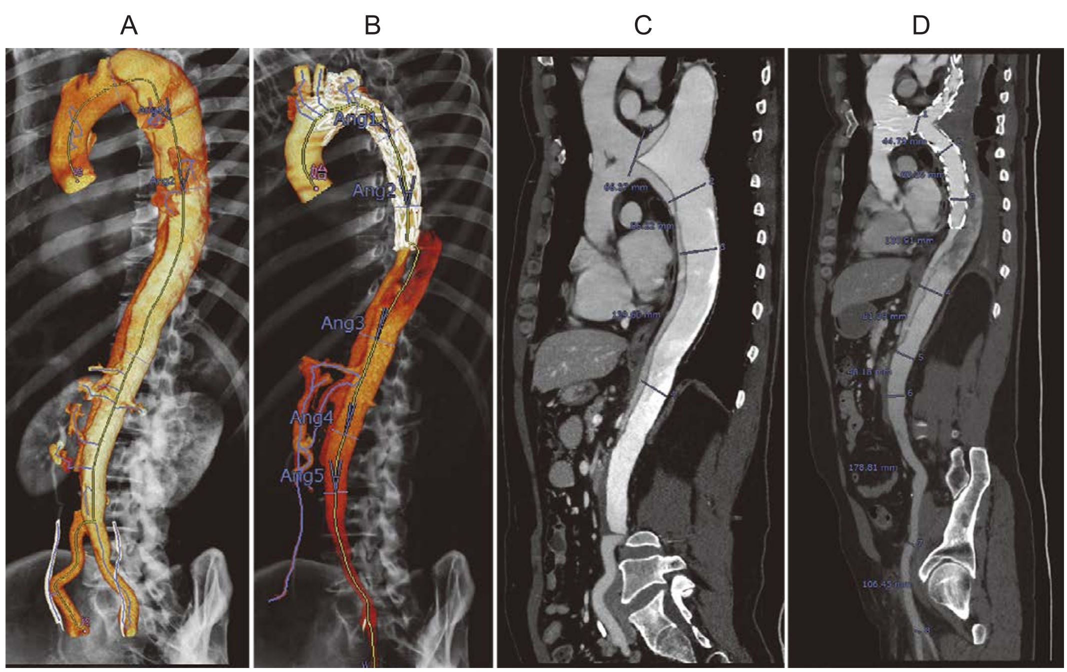

Fig. 1. Aortic evaluation using the VINCENT system before and after surgery
This case was in the late group, and 4 years after the onset, one debranching thoracic endovascular aortic repair was performed due to the enlargement of the aortic system.
A and C are preoperative images showing DeBakey IIIb false-lumen-type chronic aortic dissection.
B and D are postoperative images taken on the 26th postoperative day, and good false-lumen thrombus was observed.
A: Preoperative computed tomography (CT) (three-dimensional image).
B: Postoperative CT (three-dimensional image).
C: Preoperative CT (curved planar reconstruction image).
D: Postoperative CT (curved planar reconstruction image).

control because being able to follow it through a steep aortic arch in patients with less curvature is important to avoid causing a bird beak configuration. Before using the C-TAG with an active control, we used a C-TAG device without a bare stent on the proximal side along with a Valiant system (Medtronic, Dublin, Ireland) for its ability to follow along the proximal side. On the distal side, we placed the device in a position where avoiding the bent part of the descending aorta is possible. If we identified the artery of Adamkiewicz using contrast-enhanced CT, the device was placed without touching the artery of Adamkiewicz.

Radiological evaluations

Approximately 1 week after surgery, contrast-enhanced CT was performed to detect any endoleaks, intimal damage, thrombosis in the false lumen, and reentry patency. To evaluate remodeling of aortic aneurysms, we measured the true- and false-lumen areas at the following levels: A, immediately after branching of the left subclavian artery; B, the descending aorta at the tracheal bifurcation level; C, the descending aorta at the aortic annulus level; and D, the descending aorta at the diaphragm level (Fig. 1 and 2).

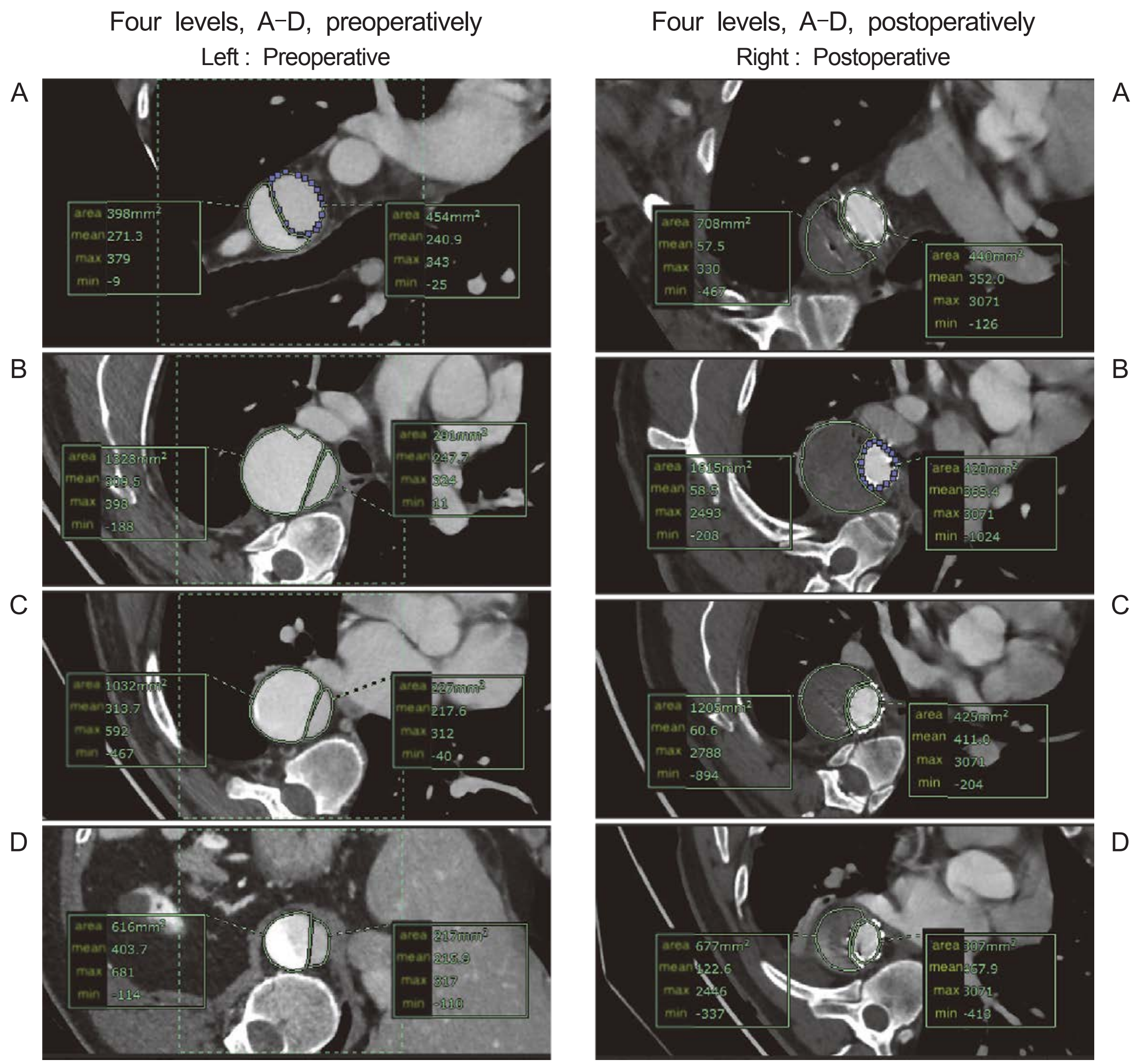

Fig. 2. Measurement of true- and false-lumen areas at each level before and after surgery
The true-lumen and false-lumen areas at each level of CT images of the same patient as in Figure 1. Postoperative false-lumen thrombus, enlargement of the true-lumen area, and reduction of the false-lumen area are observed.
Four levels for evaluation (top to bottom).
A: Immediately after branching of the left subclavian artery.
B: The descending aorta at the tracheal bifurcation level.
C: The descending aorta at the aortic annulus level.
D: The descending aorta at the diaphragm level.

Statistical evaluation

The data are presented as means±standard deviations. For statistical analysis, we used the t-test and *P* values of <0.05 were used to indicate statistical significance.

Ethical consideration

Our institutional review board (IRB) approved this study and waived the requirement for written informed consent. The ethics approval number for this study was F2020C38 at the IRB of Showa University Fujigaoka Hospital.

Results

Clinical characteristics

The rate of having a preoperative history of hypertension was high in both groups. No difference regarding the proportion of patients having diabetes, renal dysfunction, respiratory dysfunction, and cerebrovascular disorder was present between the groups (Table 1).

Periprocedural details of TEVAR

We adopted the classification proposed by Ishimaru *et al.*[9] Among the 10 patients (seven men; mean age, 60±16 years) in the early group, seven underwent zone 3 TEVAR and three underwent zone 2 TEVAR with axillo-axillary (Ax–Ax) bypass (Table 2). The mean diameter of the aortic aneurysms at the onset was 41.7±6.3 mm (Table 1). Three patients underwent TEVAR during their conservative treatment period for an enlarged aneurysm diameter (n=1), enlarged aneurysm diameter and uncontrollable pain (n=1), and asymptomatic superior mesenteric artery narrowing (n=1). One patient with an aortic diameter of 27 mm underwent TEVAR because of intermittent claudication and a decreased ankle/brachial pressure index during follow-up as a complication of TBAD. In six of the seven patients, the aortic diameter exceeded 40 mm after conservative treatment for 22 days after TBAD onset, with the operation performed during the subacute stage.

All patients in the late group were men (mean age, 52±10 years), four of who underwent zone 3 TEVAR and three underwent zone 2 TEVAR with Ax–Ax bypass (Table 2). The mean diameter of the aortic aneurysms at the time of TEVAR was 54.9±7.2 mm. Three-chamber dissection was performed in two cases. We performed the "candy plug" technique[10] in two cases to suppress the retrograde false-lumen blood flow from the abdominal aorta.

The durations from the onset of TBAD to TEVAR were 46±25 days and 7.0±5.3 years in the early and late groups, respectively. The operation times were 121±76 min and 176±65 min ($p=0.16$) in the early and late groups, respectively, and the longer operation time in the late group was due to the debranching and candy plug procedures. The mean observation periods were 38±26 months and 41±21 months, respectively. The number of stent implantations for

Table 1. Comparison of the patients' preoperative clinical characteristics between the early and late groups

	Early group (n=10)	Late group (n=7)	*P* value
Age	60±16 years	52±10 years	0.30
Day from onset	46±25 days	7.0±5.3 years	0.01
Diameter at the time of TEVAR	41.7±6.3 mm	54.9±7.2 mm	<0.01
Sex (male)	7 (70%)	7 (100%)	0.12
Prior CVA	1 (10%)	0 (0%)	0.42
Previous open surgery	0 (0%)	1 (14%)	0.24
Diabetes mellitus	0 (0%)	0 (0%)	0
Hypertension	6 (60%)	6 (14%)	0.28
CKD (Cr>1.5)	0 (0%)	0 (0%)	0
Respiratory dysfunction ($FEV_{1.0\%}$<70%)	2 (20%)	1 (14%)	0.78
Bronchial asthma	1 (10%)	1 (14%)	0.80
Rheumatism	1 (10%)	0 (0%)	0.42

CVA, cardiovascular accident; CKD, chronic kidney disease; Cr, creatinine; $FEV_{1.0\%}$, forced expiratory volume 1.0%/forced vital capacity ratio; TEVAR, thoracic endovascular aortic repair.

the two groups was 1.4±0.5 and 2.0±0.5, respectively (Table 2). The grafts used included C-TAG (n=8), Valiant (n=1), and Zenith Dissection (Cook Group, Indiana, USA) (n=1) in the early group and C-TAG (n=4), Valiant (n=1), and Zenith Dissection (n=2) in the late group.

We performed zone 2 TEVAR following Ax–Ax bypass in all cases and embolized the left subclavian artery. To prevent paraplegia, we maintained the mean blood pressure at ≥90 mmHg during the operation, and the stent insertion site was adjusted to the level of the aortic annulus as much as possible. In the late group, one patient underwent stent graft insertion to the tracheal bifurcation level, and a bare stent was inserted onto the distal side using the Provisional Extension to Induce Complete Attachment technique[11].

Radiological evaluations of TBAD pre- and post-TEVAR

In all patients, the mean time to postoperative CT was 7±2 days. In the early group, the true-lumen area was significantly increased at all levels, except for the A level—B: 381 mm^2±201 mm^2 to 576 mm^2 ±164 mm^2 ($p<0.01$); C: 266 mm^2±112 mm^2 to 471 mm^2±120 mm^2 ($p<0.01$); and D: 231 mm^2±157 mm^2 to 357 mm^2±162 mm^2 ($p<0.01$). Moreover, the false-lumen area was significantly reduced at all levels—A: 306 mm^2±238 mm^2 to 116 mm^2±147 mm^2 ($p=0.02$); B: 671 mm^2±242 mm^2 to 541 mm^2±309 mm^2 ($p=0.05$); C: 665 mm^2±197 mm^2 to 530 mm^2±217 mm^2 ($p=0.01$); and D: 532 mm^2±173 mm^2 to 432 mm^2±140 mm^2 ($p<0.01$). In the late group, the true-lumen area did not increase, except for the true-lumen area at the B level—B: 339 mm^2±70 mm^2 to 448 mm^2±70 mm^2 ($p=0.03$) (Table 3 and Fig. 3). The early group had a greater increase in the true-lumen area and reduction in the false-lumen area than the late group.

Complications and prognosis

No intraoperative or early postoperative intimal injuries; transition to thoracotomy; and postoperative paraplegia, cerebral infarction, or hospital deaths were encountered. However, intraoperative access causing vascular injury was observed in one case. We achieved entry closure in all cases, and all patients were discharged without requiring re-surgery or experiencing in-hospital death.

There was no case of SINE during the course. In the early group, one patient who underwent zone 2 TEVAR with Ax–Ax bypass using a Valiant stent complained of chest pain after discharge and developed an RTAD. In this patient, TEVAR was performed 62 days after the TBAD onset. During reoperation, the bare stent was stuck in the intima, suggesting that the bare stent was involved in the development of RTAD in this case.

Thrombosis of the false lumen was obtained in all cases at the left subclavian artery level. In patients with reentry patency, thrombosis of the false lumen was not obtained beyond the tracheal bifurcation

Table 2. Comparison of the surgical details and intraoperative complications between the early and late groups

		Early group (n=10)	Late group (n=7)	*P* value
C-TAG		8	4	0.34
Valiant		1	1	0.80
Zenith dissection		1	2	0.35
Candy plug		0	2	0.80
Operation time		121±76 min	176±65 min	0.16
Proximal landing zone	Zone 3 TEVAR	7	4	0.61
	Zone 2 TEVAR	3	3	0.61
	Zone 1 TEVAR	0	0	
	Zone 0 TEVAR	0	0	
Distal landing zone	Tracheal bifurcation level	1	0	0.42
	Aortic valve level	5	5	0.41
	Diaphragm level	2	2	0.70
Access route complication		0	1	0.24

C-TAG, TAG Conformable Thoracic Stent; TEVAR, thoracic endovascular aortic repair.

Table 3. The true- and false-lumen areas of each group

	Early group (n = 10)			Late group (n = 7)			
True-lumen area (mm^2)	Pre-TEVAR	Post-TEVAR	*P* value	Pre-TEVAR	Post-TEVAR	*P* value	*P* value*
A	593 ± 188	642 ± 141	0.24	648 ± 163	672 ± 138	0.29	0.56
B	381 ± 201	576 ± 164	< 0.01	339 ± 70	448 ± 70	0.03	0.63
C	266 ± 112	471 ± 120	< 0.01	311 ± 76	361 ± 73	0.23	0.40
D	231 ± 157	357 ± 162	< 0.01	286 ± 85	291 ± 83	0.92	0.44
False-lumen area (mm^2)	Pre-TEVAR	Post-TEVAR	*P* value	Pre-TEVAR	Post-TEVAR	*P* value	*P* value*
A	306 ± 238	116 ± 147	0.02	274 ± 287	338 ± 332	0.18	0.82
B	671 ± 242	541 ± 309	0.05	1205 ± 425	1083 ± 448	0.06	0.01
C	665 ± 197	530 ± 217	0.01	1515 ± 768	1284 ± 872	0.32	0.01
D	532 ± 173	432 ± 140	< 0.01	1054 ± 500	1096 ± 507	0.61	0.01

TEVAR, thoracic endovascular aortic repair.
*P value for the statistical difference of the pre-TEVAR values between the early and late groups.

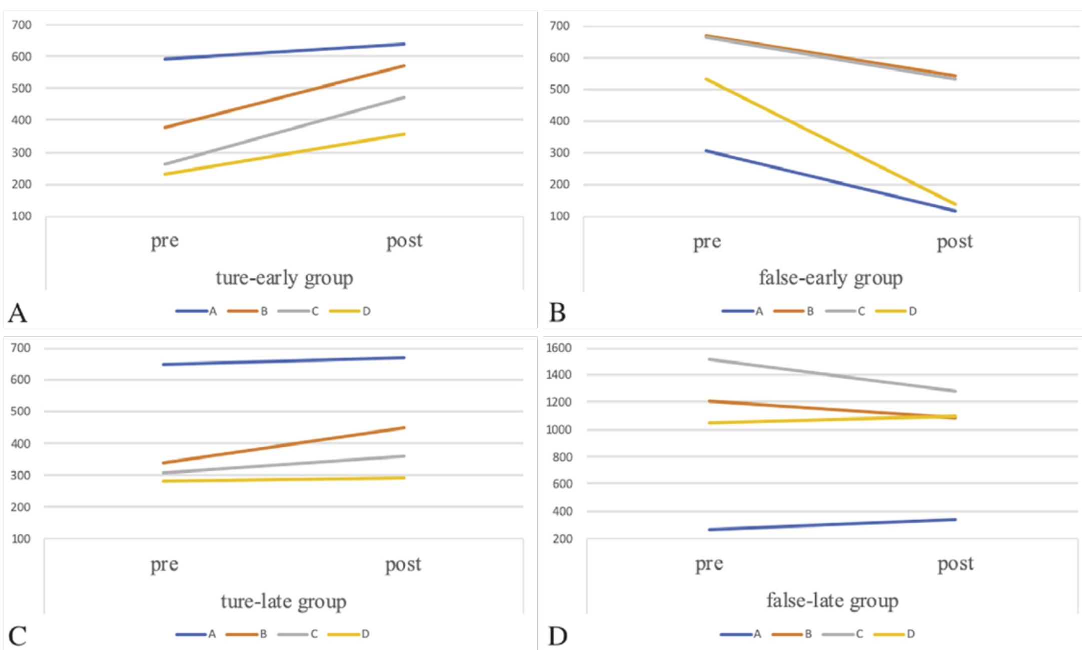

Fig. 3. Preoperative and postoperative evaluation of the true- and false-lumen areas at each level in the early and late groups
Bars A–D in the figure are immediately after left subclavian artery branching (A), the descending aorta at the tracheal bifurcation (B), the aortic annulus (C), and the diaphragm (D), respectively. The vertical axis of each figure represents the area (mm^2).
Figures A and B are graphs showing changes in the true-lumen (Fig. A) and false-lumen areas (Fig. B) before and after surgery in the early group. Figures C and D are graphs showing changes in the true-lumen (Fig. C) and false-lumen areas (Fig. D) before and after surgery in the late group.
The expansion of the true-lumen area and reduction of the false-lumen area are remarkable in the early group, but not in the late group.

level because the retrograde false-lumen blood flow remained. In the case of reentry closure, thrombosis occurred over the entire false lumen.

Discussion

Acute TBAD with severe complications (e.g., rupture, refractory pain, and organ malperfusion including the lower extremities) is associated with a poor prognosis and requires surgical treatment[12]. The factors associated with the poor prognosis of acute TBAD regarding long-term results have been reported, including an aortic maximum diameter at the onset of ≥40 mm[13], partial thrombosis of the false lumen[14], and chronic obstructive pulmonary disease[2].

The mortality rate following the surgical treatment of complicated acute TBAD was 10.1% according to the 2017 Surgical Statistics of the Japanese Association for Thoracic Surgery[12]. For DeBakey IIIb dissection, which creates entry to the distal arch aorta, closing the entry using an open stent graft is necessary, for which the in-hospital mortality rate is 16.9%[15]. Favorable treatment results for TEVAR, a minimally invasive procedure during the acute stage, have recently been reported[16–19]. Moreover, the in-hospital mortality rate, which includes patients with branch reconstruction, is 9.1%. Early closure of the entry using TEVAR accelerates aortic remodeling and prevents the enlargement of the false lumen[5], consequently improving the remote prognosis of TBAD[3,4].

Afifi *et al.* have reported that complicated acute TBAD is associated with a significantly higher rate of early mortality than uncomplicated acute TBAD[20]. Several meta-analyses have shown that the short- and medium-term prognoses of patients with uncomplicated acute TBAD treated with TEVAR are satisfactory[7,21,22]. However, dissecting aortic aneurysms appeared in the long term in ~40% of patients who underwent medical treatment during the acute phase[1,2]. The overall 5-year mortality rate for uncomplicated acute TBAD was 12.8%–13.2%[23,24].

The timing of TEVAR for uncomplicated TBAD currently depends on the facility where it is performed. Desai *et al.* have reported that patients who underwent TEVAR within 2 weeks after the onset of TBAD had more fatal complications (such as RTAD) in comparison with patients who underwent TEVAR during 2–6 weeks after the onset of TBAD because of a fragile inner membrane[6]. Moreover, they have reported that if TEVAR is performed >3 months from the onset, true-lumen enlargement and aortic remodeling after TEVAR may not be sufficient because intimal thickening and stiffening continue to progress. In one of the patients in this study, TEVAR was performed within 2 weeks following the onset of TBAD. This case was an 86-year-old female who had a history of bronchial asthma and was receiving steroids. TEVAR (entry closure) was performed using C-TAG to enlarge the aneurysm diameter during conservative treatment. The patient was discharged home 22 days after surgery without major complications. CT performed on the eighth postoperative day showed good aortic remodeling.

According to the VIRTUE registry[5], aortic remodeling in subacute patients is similar to the acute group. Therefore, we followed the strategy for performing TEVAR for uncomplicated TBAD early after conservative treatment. (However, we may have to reconsider the stent used and the operative timing, as we observed RTAD in a patient in whom TEVAR was performed 62 days after the onset of TBAD.) Our results have shown that aortic remodeling is significant in patients in whom TEVAR was performed within 3 months from the onset of TBAD; therefore, performing TEVAR within that period is necessary. Our results were almost the same as those of the VIRTUE registry[5], which showed that aortic remodeling (i.e., a decrease in the false-lumen area) was worse during the chronic phase in patients in whom TEVAR was performed 6 months after the onset of TBAD. Therefore, we concluded that early intervention with TEVAR is effective in the long term for patients with uncomplicated TBAD and who have poor prognostic factors. In contrast, effective remodeling is possible even in cases wherein TEVAR was performed ≥1 year after the onset of the disease[7]. In this study, a reduction of the false-lumen area at the C level was observed in three patients in the late group. The three patients are early cases in the late group (the period from onset of the disease is 23–48 months). Even in the late group, there were cases of remodeling, particularly the early cases. We discussed that examining the difference between cases that are remodeled and cases that are not remodeled in the late group is necessary.

In this study, we examined the frequency of aortic remodeling in the early and late groups. If the number of cases increases in the future, we will need to examine the predictive factors for aortic remodeling by dividing the late group into more detailed periods.

Patients with complete thrombosis of the false lumen have a good long-term prognosis[13,18]. In some patients with DeBakey IIIb dissection, both entry and reentry can be covered using a stent graft, and complete thrombosis of the false lumen could be easily obtained. However, covering reentry near the abdominal aortic branches is difficult. We placed the stent graft as short a range as possible to prevent paraplegic complications; hence, the insertion was limited to the level of the aortic annulus. Therefore, reentry remained in most cases, and although the false-lumen area was significantly reduced in the early group, complete false-lumen thrombosis was not attained. If appropriate remodeling is obtained in the long term, it may be reduced, but an aneurysm could still form at sites where false-lumen thrombosis is not complete. Even if surgery is required, it may be possible to respond to a Crawford VI aneurysm but not a more widespread Crawford II aneurysm. Therefore, we believe that early closure using TEVAR is useful.

Limitations of this study

The first limitation of this study is that it is a retrospective study involving a small number of cases. In addition, it is a comparison using only CT immediately after surgery. Half-year and one-year remodeling will be an issue for future consideration.

The second limitation of this study is selection bias because TEVAR is a relatively new treatment and it has actively intervened in previously followed up cases. The early group underwent TEVAR immediately after the onset because TEVAR has become widespread in Japan recently and is relatively easy to conduct. The late group postponed the TEVAR procedure at the onset of TBAD because TEVAR could not be indicated because it is a new treatment that has emerged in the last decade. The late group was indicated for treatment because it had passed without complications such as aortic rupture and re-dissection, but it gradually expanded.

We should present the CT parameters immediately after the onset of TBAD compared with those just before TEVAR in the late group. However, we could not present these parameters because many patients were diagnosed at another medical institution and were referred to us with an aortic diameter enlargement, and many of them did not have images immediately after the onset of TBAD.

Conclusion

At present, TEVAR is the first-line treatment for complicated acute or chronic TBAD because it is minimally invasive and uses advanced devices. We believe that TEVAR is a useful treatment strategy for treating dissections when performed early after onset. After applying TEVAR, good aortic remodeling was obtained within 3 months after the TBAD onset. Because the number of cases is small and the result is early outcome, further studies and careful follow-up of long-term remodeling and prognoses are necessary.

Conflict of interest disclosure

The authors declare no conflicts of interest regarding this study.

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