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Thoracic Endovascular Aortic Repair for Chronic DeBakey IIb Aortic Dissection

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Abstract

Background—Thoracic endovascular aortic repair (TEVAR) for chronic DeBakey IIb dissection with associated descending aneurysm remains controversial. This study examines long-term results of TEVAR for this disorder including examination of anatomic features associated with TEVAR outcomes.

Methods—Between July 2005 and January 2013, 32 patients underwent TEVAR for chronic (>30 days) DeBakey IIb dissection involving the descending thoracic aorta at a single institution and constituted the study cohort.

Results—The mean interval from dissection to TEVAR was 32 ± 44 months (range, 1 to 146 months). There were no 30-day or in-hospital deaths, strokes, or paraplegia. During a 54-month median follow-up, there were no aortic-related deaths. Significant thoracic aneurysm sac regression (>1 cm) in the intervened segment was observed in 89%. Thoracic remodeling was not correlated with the number of visceral vessels arising from the true lumen or the number or size of residual distal fenestrations; failure of thoracic remodeling was associated with fenestrations distal to the endograft(s) in the descending thoracic aorta, most often stent graft-induced new entry tears. Complete resolution of the thoracic and abdominal false lumen after TEVAR was observed in 15.6% ($n = 5$). All patients in this group had all visceral vessels arising from the true lumen and fewer than three residual distal fenestrations.

Conclusions—Thoracic endovascular aortic repair is effective for chronic DeBakey IIb dissection with associated descending aneurysm, with excellent 30-day and long-term outcomes and significant aortic remodeling in the vast majority of patients. Thoracic remodeling does not appear dependent on distal anatomic characteristics of the true and false lumens, although care should be taken to cover all thoracic fenestrations and avoid creation of stent graft-induced new entry tears to ensure clinical success. Complete aortic remodeling was observed only in the setting of all visceral vessels off the true lumen with fewer than three residual distal fenestrations, and this would appear the ideal anatomy for TEVAR in this scenario.

At least one third of patients treated medically for uncomplicated acute type B aortic dissection (TBAD) will require surgery for aortic-related complications within 5 years of their dissection event. Most commonly, surgery is required for aneurysmal dilation of the chronically dissected thoracic aorta, and once the aortic diameter exceeds 55 to 60 mm, the risk of rupture is estimated at 30% per year [1]. As a result of reduced early mortality and morbidity versus open surgery, thoracic endovascular aortic repair (TEVAR) has been recommended by some [1] for management of these so-called chronic complicated aortic dissections [2], although the results of TEVAR for chronic dissection have been mixed [3–12] and significant controversy remains regarding optimal treatment strategy for these patients, especially those with DeBakey IIIb dissections involving both the thoracic and abdominal aorta.

Our group [4] has previously published results of TEVAR for chronic TBAD with secondary aneurysmal degeneration with excellent short-term and midterm outcomes. However, this study, like others in the literature [3, 5–12], has the primary limitation of including a heterogeneous mix of DeBakey IIIa dissections confined to the chest, hybrid repairs, and more extensive DeBakey IIIb dissections. As such, prior work fails to truly evaluate the efficacy of TEVAR for chronic DeBakey IIIb dissection. Further, there has been a great deal of recent work [13, 14] examining the effect of variations in the size and location of intimomedial tears in TBAD on subsequent aortic dilation, as well as increased recognition that creation of so-called stent graft-induced new entry tears (SINE) [15, 16] may contribute to therapeutic failure after TEVAR. Consequently, the current study sought to examine long-term results of TEVAR for chronic DeBakey IIIb dissection with associated descending aneurysm, including detailed examination of anatomic features associated with TEVAR outcomes, to critically assess the role of TEVAR in management of this disease.

Material and Methods

Patient Population and Data Collection

This study was approved by the institutional review board, and the need for individual patient consent was waived. A query of the Duke Thoracic Aortic Surgery Database identified 32 patients who underwent TEVAR for chronic DeBakey IIIb dissection with associated descending aneurysm during the study interval of July 2005 to January 2013. All had a patent false lumen (FL) extending from the thoracic aorta to distally below the celiac axis; patients with intramural hematoma and no patent FL were excluded, as were those undergoing hybrid procedures other than carotid–subclavian bypass. Chronic was defined as 30 days or longer from the index dissection event [17].

All outcomes and complications were prospectively recorded, and all patients had lifelong follow-up at the Duke Center for Aortic Disease [2, 4]. Post-TEVAR computed tomography (CT) scans were performed with arterial phase and delayed contrast thin-cut imaging to assess for endoleak as well as FL patency, given the known inability to fully detect persistent FL perfusion if delayed contrast imaging is not performed [4, 5].

Detailed examination of anatomic features associated with TEVAR outcomes was performed by 2 independent blinded observers using multiplanar thin-cut CT angiography

images from the first postoperative study. Computed tomography angiography analysis was performed on a TeraRecon Aquarius iNtuition 3D-workstation (TeraRecon Inc, San Mateo, CA). Specific assessments included the number of visceral vessels arising from the true lumen (TL), the number of residual fenestrations distal to the implanted thoracic endograft(s), including the number in the thoracic, abdominal, and iliac segments, and the number of residual distal fenestrations of 10 mm or greater in diameter as fenestrations this size are associated with more-rapid FL expansion or aortic growth after TBAD [13]. Each patient's last postoperative CT angiography was used to assess for aortic remodeling and FL patency status. False lumen patency was graded from 0 to III according to the previously published Parsa score [2].

Operative Technique

Following US Food and Drug Administration approval in 2005, TEVAR became the preferred treatment at our institution for chronic TBAD patients with suitable anatomy [18] owing to excellent procedural and midterm outcomes [2, 4]. Indications for repair included rapid aneurysm enlargement (>5 mm in 6 months) or maximal aortic diameter of 5.5 cm or greater. Conventional open surgery was reserved for patients with a connective tissue disorder or anatomy unsuitable for TEVAR, such as those with thoracoabdominal aneurysm in which the aorta remains significantly dilated at the level of the celiac axis. Our technique for TEVAR in chronic TBAD has recently been published [18].

Statistical Analysis

The Social Security Death Index was queried to confirm all deaths and survey patients lost to follow-up. Survival analyses were performed using Kaplan-Meier method. To analyze the association of examined anatomic features on aortic remodeling and TEVAR outcomes, a Wilcoxon-Mann-Whitney test was used given nonparametric data. All calculations were performed using R version 3.0.1 (Vienna, Austria).

Results

Patient Demographics and Operative Characteristics

Patient demographics are presented in Table 1. The primary tear was in the proximal descending thoracic aorta in 25 patients (78%) and mid-descending thoracic aorta in 7 patients (22%). No patient had a thoracoabdominal aneurysm, and mean preoperative aortic diameter at the celiac axis was 3.5 ± 0.5 cm (range, 2.4 to 4.4 cm). Eight cases (25%) were urgent because of acutely symptomatic aneurysms. Average preoperative maximal aortic diameter was 5.7 ± 1.1 cm. Mean interval from initial dissection to TEVAR was 32 ± 44 months (range, 1 to 146 months). The left subclavian artery was partially or fully covered (zone 2 proximal landing zone [PLZ]) in 26 patients (81.3%), of whom 5 patients (19.2%) underwent adjunctive left carotid-subclavian bypass for previously described indications [19]. Cerebrospinal fluid drainage was used selectively in 3 patients (9.4%) for previously described indications [20]. The mean number of endografts per case was 1.6 ± 0.8 (range, 1 to 4), and median endograft length was 20 cm. The mean length of thoracic aortic coverage was 22.6 ± 6.4 cm. All commercially available endografts were used during the study period, including Gore TAG (W.L. Gore & Assoc, Flagstaff, AZ; $n = 21$ [65.6%]), Gore C-

TAG (W.L. Gore & Assoc; n = 3 [9.4%]), Zenith TX2 (Cook Medical Inc, Bloomington, IN; n = 6 [18.8%]), and Medtronic Talent (Medtronic Endovascular, Santa Rosa, CA; n = 2 [6.3%]).

Procedural (30-Day or In-Hospital) and Follow-Up Outcomes

There were no 30-day or in-hospital deaths, strokes, or paraplegia. Two patients (6.3%) experienced retrograde type A dissection. Both occurred with Zenith TX2 devices, which have proximal barbs for fixation, and with zone 2 PLZ. Both patients underwent successful repair. Median postoperative length of stay for the entire cohort was 3 days (range, 1 to 14 days).

Over a median follow-up of 54 months (interquartile range [IQR], 24.8 to 72.0 months), there were no aortic-related deaths. Of the 8 late deaths, 6 were cardiopulmonary, 1 was secondary to cancer, and 1 from a drug overdose. Five patients (15.6%) required reintervention within the originally treated thoracic aortic segment because of SINE at the distal end of the most distal endograft in 3 patients, uncovered distal thoracic fenestrations in 1 patient, and late (31 months) type Ia endoleak owing to PLZ dilation in 1 patient. Reinterventions in the 4 patients with SINE or uncovered distal thoracic fenestrations were all distal TEVAR extensions to cover the tears (Fig 1), whereas the type Ia endoleak required hybrid arch repair. This was the only type I endoleak in the series (3.1% incidence). There was no in-hospital mortality after reintervention. Two patients (6.3%) required late open repair for aneurysmal dilation of the residually dissected abdominal aorta at 15 and 91 months postoperatively. Overall actuarial survival is 71.2% at 72 months (Fig 2).

Previous work has demonstrated that significant aortic remodeling with FL or aneurysm sac regression in patients with chronic dissection is not typically observed until 6 to 12 months after TEVAR [2, 4]; of the 32 patients in the current series, 27 patients (84%) had at least one follow-up CT scan performed at greater than 6 months postoperatively, and this cohort was used to analyze for aortic remodeling. Of the 5 patients without imaging at greater than 6 months postoperatively, 2 patients died as a result of cardiopulmonary etiology less than 12 months postoperatively, and the other 3 patients failed to return for follow-up despite multiple attempts to arrange repeat imaging; these 3 patients all remain alive at 21, 69, and 93 months from their original TEVAR based on phone contact or Social Security Death Index review. Of the 27 patients with imaging at greater than 6 months postoperatively, significant aortic remodeling with aneurysm sac regression (1 cm thoracic aneurysm diameter reduction) in the intervened-on aortic segment was observed in 24 of 27 patients (89%). Of the 3 patients without sac regression, all had anatomic explanations including type II endoleak (n = 1), persistent sac perfusion through distal SINE (n = 1), and uncovered distal thoracic fenestrations (n = 1).

The extent of FL thrombosis at the last radiographic follow-up is presented in Table 2. Overall, 19 of 32 patients (59.4%) have thrombosis of at least the entire thoracic FL (Parsa scores II and III) at latest follow-up based on both arterial phase and delayed contrast imaging. Five patients (15.6%) had complete aortic remodeling with resolution of the entire thoracic and abdominal FL (Parsa score III) after TEVAR.

Anatomic Features Associated With Thoracic Endovascular Aortic Repair Outcomes

Ten patients (31.3%) had all visceral vessels arising entirely from the TL, 11 patients (34.4%) had three visceral vessels arising from the TL, 8 patients (25.0%) had two visceral vessels arising from the TL, and 3 patients (9.4%) had one visceral vessel arising entirely from the TL. No patient had all four visceral vessels arising entirely from the FL. As measured on the first postoperative follow-up CT angiography, the mean number of fenestrations within the aorta and iliac arteries distal to the endografts was 2.7 ± 2.1 (range, 0 to 11). When comparing the 24 patients experiencing significant thoracic aneurysm sac regression in the intervened-on segment with the 3 patients without significant sac regression on CT angiography imaging at greater than 6 months after TEVAR, there was no difference in the number of visceral vessels arising from the TL (3 [IQR, 2 to 4] versus 3 [IQR, 2.5 to 3.5]; $p = 0.94$), the number of residual fenestrations distal to the implanted endograft(s) (2.5 [IQR, 2 to 3] versus 1 [IQR, 0.5 to 1.5]; $p = 0.07$), or the number of residual distal fenestrations measuring 10 mm or greater in diameter (0 [IQR, 0 to 0] versus 0 [IQR, 0 to 0]; $p = 0.52$). However, when comparing those patients ($n = 5$) with complete aortic remodeling (Parsa score III) after TEVAR with those with persistent FL perfusion along any segment of the aorta (Parsa score 0 to II; $n = 27$; Table 3), those with complete FL resolution had a significantly greater number of visceral vessels arising from the TL and significantly fewer residual distal fenestrations. Specifically, all patients with complete FL resolution had all visceral vessels arising from the TL and three or fewer residual distal fenestrations. There was no association with the number of distal fenestrations of 10 mm or greater, although only three residual fenestrations of this size were noted in the entire series. Two patients (6.3%) had 5 distal fenestrations or greater within the abdominal aorta and iliac arteries, and both required open repair for aneurysmal dilation of the residually dissected abdominal aorta at 15 and 91 months postoperatively as outlined earlier.

Comment

Because of reduced early mortality and morbidity as compared with open surgery, there has been increasing interest in TEVAR for management of chronic complicated TBAD [1]. However, results of TEVAR for chronic TBAD have been mixed [2–12], and controversy remains regarding the optimal treatment strategy for these patients, especially those with DeBakey IIIb dissections involving the thoracic and abdominal aorta. The current study supports TEVAR as an effective therapy for chronic DeBakey IIIb patients with appropriate anatomy, namely isolated descending aneurysm and not thoracoabdominal aneurysm, with excellent 30-day and long-term outcomes. Significant aneurysm sac regression (1 cm) in the intervened-on segment was observed in nearly all patients with imaging follow-up beyond 6 months, with an anatomic explanation in those few without observed regression.

Thoracic endovascular aortic repair does not induce total aortic remodeling with complete resolution of the thoracic and abdominal FL in most patients (only 16% experienced complete FL resolution, ie, Parsa score III, in the current series), and this outcome appears to occur only in the setting of all visceral vessels arising from the TL and with three or fewer residual fenestrations downstream from the implanted endograft(s). Despite this lack of complete resolution of the FL, TEVAR appears effective in avoiding late aorta-related

death, with 100% aorta-specific survival at 72 months, and avoidance of aortic-related mortality is the primary goal of therapy, as noted by others [5, 12]. The reason for the avoidance of late aortic rupture despite a patent downstream abdominal FL would appear to be that the residually dissected abdominal aorta does not undergo aneurysmal degeneration in most patients [21], and when it does (6% of patients in the current series), secondary reintervention with either open or hybrid thoracoabdominal repair can be performed by using the previously implanted endografts to either sew a Dacron graft to or as the PLZ in the case of hybrid repair. In essence, by having undergone prior TEVAR, those few patients progressing to late thoracoabdominal aneurysm will require only Extent III or IV repair, rather than Extent II repair with its greater risk of perioperative morbidity and mortality [22].

The risk of late aneurysmal degeneration of the abdominal aorta (visceral segment, infrarenal segment, or iliac arteries) appears to be predicted by the presence of greater than five distal fenestrations within the abdominal aorta and iliac arteries based on the results of the current study, and therefore these patients should have particularly close follow-up to assess for need for late reintervention, or, alternatively, consideration should be given to more aggressive endovascular intervention at the initial repair such as placing covered stents within the abdominal aorta or iliac arteries to cover distal fenestrations in an attempt to reduce this risk of late aneurysmal degeneration. Although not assessed in the current study, we have now begun to adopt this approach in both the acute and chronic setting to reduce late abdominal aortic dilation, and additional work is needed to assess the efficacy of this approach.

Since the time of our prior publication on this subject [4], a number of other groups [3, 5–12] have published results with TEVAR for chronic complicated TBAD. These studies, similar to the current one, have generally reported excellent 30-day outcomes with especially low rates of neurologic complications. The one outlier with regard to neurologic complications is the recent report by Scali and colleagues [12] of 88 patients with chronic TBAD undergoing TEVAR with a greater than 13% combined paraplegia and stroke rate. The reasons for this discordant report are unclear, but may be related to inclusion of a significant number of higher-risk hybrid repairs in their cohort.

Another common theme among the published reports is that most authors [6, 7, 10, 11] have come to the conclusion that longer thoracic aortic pavement at the initial TEVAR procedure is associated with better outcomes and reduced need for reintervention. The results of the current study are concordant with these prior findings, as four of five (80%) reinterventions within the thoracic aorta were for either SINE or dissection-induced fenestrations not covered at the original procedure. For these reasons, we now generally pave down to the celiac axis at the initial procedure. We also use endografts sized distally to the smaller TL in an attempt to avoid creating SINE, which will result in treatment failure, as prior work has demonstrated that stress produced by the endograft appears to play a predominant role in the occurrence of SINE [15]. Specifically, as emphasized by Weng and colleagues [16], excessive oversizing of the endograft relative to the TL area is a significant factor causing delayed distal SINE and precise size selection is crucial for the distal end of the endograft. They also suggest an implantation sequence of distal smaller-sized stent grafts first followed

by larger proximal devices second, and this has evolved into our typical deployment sequence whereby smaller, usually tapered lower radial force devices are placed with the distal seal just above the celiac axis in the TL with subsequent distal to proximal deployment, frequently using multiple tapered devices, up to the level of the PLZ. Although this distal to proximal deployment sequence is not recommended in the setting of acute TBAD because of concerns over compressing the distal FL without first covering the primary tear and excluding FL inflow, we have found the reverse deployment sequence to work well without complications in the chronic setting, presumably because of the thickened dissection membrane, which does not immediately reexpand the TL. Given these anatomic complexities, along with recent Food and Drug Administration approval of TEVAR for both acute and chronic TBAD, newer devices are needed to specifically address the unique requirements for treating dissection pathology, including longer tapered devices with lower radial force and absence of barbs or proximal bare metal stents to minimize the risk of retrograde type A dissection and SINE.

The current study is the first to examine in detail anatomic features of the aorta and branch vessels as they relate to aortic remodeling and FL thrombosis after TEVAR for chronic TBAD. One prior study has examined features similar to those in the current report, and with remarkably similar results, in patients undergoing TEVAR for acute TBAD. Qin and colleagues [23] found that all patients with complete thrombosis of the FL (Parsa score III) after TEVAR for acute TBAD had all visceral vessels arising from the TL; complete FL thrombosis patients also had significantly fewer distal reentry tears than those maintaining FL patency. These findings are essentially identical to those of the current report in chronic dissection patients, and the similarity of the results may be attributable to the fact that prior work has demonstrated no significant difference in the number, size, or location of intimomedial tears between acute and chronic dissections [24].

Although the number of visceral vessels arising from the TL as well as the number of residual distal fenestrations after TEVAR was associated with greater total aortic remodeling and FL thrombosis, these features did not appear to have any effect on whether or not the aneurysm developing adjacent to the primary tear in the intervened-on thoracic segment underwent significant reverse remodeling in the current study. One potential explanation for this finding may be recent in vitro phantom data demonstrating that during systole, flow enters the FL through all tears simultaneously, whereas during diastole it leaves through all communications [14]. As such, flow in the FL is principally to-and-fro locally, rather than from proximal to distal or vice versa, and therefore as long as the primary tear and all thoracic fenestrations are covered, there should not be significant retrograde flow from the abdominal aorta up into the thoracic segment. Previous work from our group using wireless pressure measurement systems placed directly into the thoracic FL at the time of TEVAR is consistent with this hypothesized lack of significant retrograde flow, as pressure within the thoracic FL was only $14\% \pm 5\%$ of systemic pressure at latest follow-up as measured by the implanted sensors [4].

In conclusion, TEVAR is an effective treatment for chronic DeBakey IIIb dissection with associated descending aneurysm with excellent 30-day and long-term outcomes and significant aortic remodeling in the vast majority of patients. Thoracic remodeling does not

appear to be dependent on distal anatomic characteristics of the TL and FL, although care should be taken to cover all thoracic fenestrations and avoid creation of distal SINE to ensure clinical success. Complete aortic remodeling was observed only in the setting of all visceral vessels off the TL with three residual distal fenestrations or fewer, and this would appear to represent the ideal anatomy for TEVAR in this scenario.

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Fig 1.

(A) Computed tomography angiography images from a patient early in the series who underwent thoracic endovascular aortic repair for a proximal descending aneurysm developing adjacent to the primary tear. The preoperative image (left) demonstrates a small diameter true lumen (TL) in the planned distal landing zone in the mid-descending thoracic aorta, and the postoperative image (right) shows a stent graft-induced new entry tear (SINE) at this level caused by tearing of the dissection membrane by the distal end of the device, which was excessively oversized relative to the true lumen diameter. (B) Three-dimensional reconstruction computed tomography angiography image demonstrating significant perfusion of the false lumen via the stent graft-induced new entry tear 1 month after thoracic endovascular aortic repair. (C) Reintervention with a distal extension prosthesis to exclude the stent graft-induced new entry tear was performed, and three-dimensional reconstruction computed tomography angiography 6 years after reintervention demonstrates clinical success with near complete resolution of the thoracic false lumen with persistent abdominal dissection but normal distal aortic diameters.

Fig 2.
Actuarial (Kaplan-Meier) overall (solid line) and aorta-specific (dashed line) survival.

Table 1Demographics^a

Variable	Patients (n = 32)
Age (y)	57.9 ± 11.7
Male	22 (68.8%)
White race	13 (40.6%)
Body mass index (kg/m ²)	29.4 ± 6.2
Hypertension	31 (96.9%)
Hyperlipidemia	16 (50.0%)
Tobacco use	19 (59.4%)
Diabetes	5 (15.6%)
Coronary artery disease	2 (6.3%)
COPD	6 (18.8%)
Baseline creatinine >1.5 mg/dL	5 (15.6%)

^aValues expressed as mean ± standard deviation or number (percent).

COPD = chronic obstructive pulmonary disease.

Table 2

Extent of False Lumen Thrombosis at Last Radiographic Follow-Up

Extent FL Thrombosis ^a	Chronic IIIB repair (n = 32)
0	8 (25.0%)
I	5 (15.6%)
II	14 (43.8%)
III	5 (15.6%)

^aParsa classification [2] of false lumen (FL) thrombosis: 0, any retrograde FL perfusion along endograft(s); I, thrombosis along length of endograft(s); II, entire thoracic FL thrombosis; III, entire aortic FL thrombosis.

Table 3

Comparison of Anatomic Features Between Those With (Parsa III) and Without (Parsa 0 to II) Complete False Lumen Resolution^a

Variable	Overall (n = 32)	Parsa 0/I/II (n = 27)	Parsa III (n = 5)	p Value
Number of visceral vessels arising from TL	3 [2, 4]	3 [2, 3.5]	4 [3.5, 4]	0.022
Total number of distal fenestrations	2 [1.8, 3]	2 [2, 3]	1 [0, 2]	0.055
Number of distal fenestrations 10 mm diameter	0 [0, 0]	0 [0, 0]	0 [0, 0]	0.472

^aValues represent median [interquartile range].

TL = true lumen.