Preoperative thoracic false lumen branches are predictors of aortic enlargement after stent grafting for DeBakey IIIb aortic dissection

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ABSTRACT

Objective: The study objective was to assess the effect of preoperative thoracic false lumen branches on thoracic aortic enlargement along the stent graft after thoracic endovascular aortic repair for DeBakey IIIb aortic dissection.

Methods: From January 2011 to December 2013, 67 patients who underwent thoracic endovascular aortic repair for DeBakey IIIb aortic dissection were retrospectively investigated. We assessed preoperative thoracic false lumen branches and diameter measurements at the level of the tracheal carina. Patients with a median follow-up of 12.2 months (interquartile range, 4.3-26.6 months) were categorized into 2 groups based on a receiver operating characteristic curve analysis: group A (preoperative thoracic false lumen branches ≥ 8 , $n = 28$) and group B (preoperative thoracic false lumen branches < 8 , $n = 39$). Diameter changes over time were evaluated using a mixed model approach. A multivariate Cox regression analysis was used to study the influence of the preoperative thoracic false lumen branches on thoracic aortic enlargement along the stent graft.

Results: Six patients experienced thoracic aortic enlargement along the stent graft during follow-up (6 in group A, 0 in group B). The cumulative thoracic aortic enlargement along the stent-graft rate was higher in group A than in group B (log-rank $P < .01$). Diameter data showed significantly more reduction of the thoracic false lumen from preprocedure to 12 months in group B than in group A (change difference, 2.51; standard error, 0.99; $P = .01$). Complete false lumen thrombosis was more prominent in group B than in group A at each follow-up time point. After multivariate adjustment, preoperative thoracic false lumen branches were associated with thoracic aortic enlargement along the stent graft (hazard ratio, 2.92; 95% confidence interval, 1.06-8.01).

Conclusions: Preoperative thoracic false lumen branches are a morphologic predictor of thoracic aortic enlargement along the stent graft in DeBakey IIIb aortic dissection after thoracic endovascular aortic repair. (*J Thorac Cardiovasc Surg* 2018;155:21-9)

Thoracic endovascular aortic repair (TEVAR) has been accepted as an effective treatment option for patients with DeBakey III aortic dissections.¹⁻⁷ During the procedure,

perfusion of the false lumen is eliminated by the closure of the proximal entry tear, and false lumen thrombosis is induced. Eventually, thrombus regression results in aortic remodeling and prevents late enlargement.⁸⁻¹¹ The most prominent aortic remodeling mainly occurs in

The anatomic basis of continuous perfusion of the thoracic aortic false lumen.

Central Message

Preoperative TFLBs are a predictor of the TAES in DeBakey IIIb aortic dissection after TEVAR.

Perspective

Preoperative TFLB was identified as a prognostic factor for thoracic aortic enlargement after TEVAR in DeBakey IIIb aortic dissection. This may help to identify patients at a higher risk of postoperative thoracic aortic enlargement by imaging scan performed before endovascular therapy.

See Editorial Commentary page 30.

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Abbreviations and Acronyms

CI	= confidence interval
CTA	= computed tomography angiography
HR	= hazard ratio
SE	= standard error
TAES	= thoracic aortic enlargement along the stent graft
TEVAR	= thoracic endovascular aortic repair
TFLB	= thoracic false lumen branch

the stent-graft-covered segment.¹⁰⁻¹² However, a Swedish multicenter study demonstrated that approximately 5% of patients had thoracic aortic enlargement along the stent graft (TAES) during follow-up.¹³

Persistent false lumen flow is a major factor for unfavorable aortic remodeling.^{14,15} One possible contributing factor for persistent retrograde false lumen flow along the stent-graft-covered segment after TEVAR is abdominal reentry tears.^{16,17} In addition, based on the principle of flow continuity, the outflow has an effect on maintaining the patency of the false lumen.¹⁸ Kolbel and colleagues¹⁹ and Song and colleagues²⁰ proposed that intercostal and bronchial arteries originating from the thoracic false lumen may play the roles of outflow tracts, leading to chronic aortic dissection, which limits the response to standard TEVAR. However, there is a paucity of clinical data to assess the association between preoperative thoracic false lumen branches (TFLBs) and aortic remodeling along the stent-graft-covered segment.

In this study, we evaluated the association between preoperative TFLBs and postoperative TAES in DeBakey IIIb aortic dissection and investigated the effect of TFLBs on aortic remodeling of the segment along the stent graft after TEVAR.

MATERIALS AND METHODS

Study Population

From January 2011 to December 2013, 245 consecutive patients underwent TEVAR for DeBakey IIIb in our institution. To minimize the potential impact of endoleak on thoracic aortic remodeling, patients with partial or complete left subclavian artery coverage by stent graft ($n = 127$) or with type I endoleak during follow-up ($n = 6$) were excluded. Patients secondary to trauma or connective tissue disease were excluded ($n = 26$). A total of 19 patients were not eligible for the analysis because of missing computed tomography angiography (CTA) data. Ultimately, 67 patients were enrolled in this study. Demographic and clinical information, operative details, and follow-up data were obtained retrospectively. This study was approved by the Institutional Review Board of the Chinese PLA General Hospital, and written informed consent was obtained from all patients.

Thoracic Endovascular Aortic Repair and Adjunctive Procedures

Fifty patients were treated in the acute setting (defined as ≤ 14 days from symptom onset), and 17 patients were treated in the chronic setting (defined as >14 days from symptom onset).²¹

The indications for TEVAR in the 42 patients with complicated dissections, 33 patients in the acute phase, and 9 patients in the chronic phase were signs of rupture and impending rupture (hemothorax, increasing peri-aortic, mediastinal hematoma, and pleural effusion), persistent or recurrent pain, hypertension refractory to medical treatment, malperfusion syndrome (acute limb ischemia, bowel ischemia, and renal ischemia), or early enlargement of the false lumen.²² Endografting procedure was used routinely for uncomplicated dissections in our center to facilitate aortic remodeling and prevent long-term adverse events; 25 uncomplicated patients underwent TEVAR in total, with 17 in the acute phase and 8 in the chronic phase.

TEVAR and all adjunctive procedures performed in our institution were conducted as previously described.²³ The following commercially available stent grafts were used: Zenith TX2 (COOK, Bjaeverskov, Denmark) ($n = 16$); Valiant (Medtronic, Santa Rosa, Calif) ($n = 13$); Hercules (Microport, Shanghai, China) ($n = 22$), and Ankura (Lifetech, Shenzhen, China) ($n = 16$). Adjunctive distal restrictive bare stents were used in 7 patients for the prevention of distal stent-graft-induced new reentry.²⁴ The stents were placed in the visceral or iliac arteries when necessary. After discharge, patients were instructed to return to undergo CTA at intervals of 6 and 12 months and annually thereafter. Postoperative arterial- and delayed-phase CTA were performed to assess for false lumen patency and endoleak.^{25,26}

Imaging Measurements

CTA images performed between the time of discharge and May 2014 or death were collected retrospectively. The serials of CTA images available for analysis at 6 ± 3 months, 12 ± 3 months, and 24 ± 6 months were 67, 45, and 25, respectively. The CTA images (slice spacing, 0.6-1.5 mm) were transferred to a 3mensio Workstation (version 6.1; 3mensio Medical Imaging BV, Maastricht, Netherlands) for semiautomatic diameter measurement with a central lumen line method. Two experienced, independent physicians blinded to the clinical information evaluated the morphologic features. Observer variability was estimated by examining the levels of intraobserver and interobserver agreement, according to Bland and Altman,²⁷ and the result confirmed small mean differences in terms of its clinical relevance.

The maximum diameter of the entire aorta and the largest short-axial diameter of the true and false lumens were measured at the level of the tracheal carina of the trachea, perpendicular to the central lumen line.²⁸ TAES was defined as an increase in maximum aortic diameter greater than 5 mm at a given follow-up time point compared with the measurement obtained during the preoperative examination.^{13,29,30} Thoracic aortic stabilization was defined as the maximum aortic diameter increasing less than 5 mm, decreasing, or remaining unchanged. The degree of thoracic false lumen thrombosis was classified as patent, partial, or complete.¹⁴ Preoperatively, measurements were obtained throughout the entire descending thoracic aorta. Postoperatively, these measurements were obtained only in the stent-graft portion of the aorta.

The following specific variables were assessed on the axial slices of preoperative CTA images: the number of TFLBs along the descending thoracic aorta, the number of abdominal false lumen small branches along the abdominal aorta, and the number of visceral branches that arose partially or completely from the false lumen. Preoperative TFLBs were identified in cases in which the false lumen vascularized the following branches: bronchial arteries, mediastinal arteries, esophageal arteries, pericardial arteries, superior phrenic arteries, and posterior intercostal arteries (Figure 1, A-C). The length of dissected aorta and height index were defined as the length of the dissected aorta divided by the body height in an attempt to reduce the impact of body height heterogeneity in individuals. Retrograde type A dissections after TEVAR in our study were symptomatic, and CTA images after onset were excluded.

Statistical Analysis

Two comparison groups were created on the basis of the results of our time-dependent receiver operating characteristic curve analysis. The

FIGURE 1. Axial image of CTA shows the TFLBs. A, Preoperative left and right bronchial arteries (*arrow*) arising from the false lumen. B, Preoperative esophageal artery (*arrow*) arising from false lumen. C, Preoperative posterior intercostal arteries (*arrow*) arising from false lumen. D, Postoperative posterior intercostal arteries (*white arrow*) arising from a partially patent false lumen (*black arrow*). TL, True lumen.

receiver operating characteristic curve for TAES had an area under the curve of 0.864 (Figure E1). The number of preoperative TFLBs at an optimal cutoff value of 8 had a high sensitivity (100%) and specificity (69.4%) for TAES. All the patients were divided into the following 2 groups according to this value: group A (preoperative TFLBs ≥ 8) and group B (preoperative TFLBs < 8). A mixed model approach was used to analyze the changes in aortic diameter over time. Kaplan–Meier analysis was performed to determine the cumulative incidence of TAES.

A multivariate Cox proportional hazards regression analysis was performed to investigate the association between preoperative TFLBs and TAES. Covariate identification was based on a 10% change-in-estimate criterion.³¹ Variables that changed the coefficient of TFLBs by at least 10% were accepted as covariates for multivariate Cox proportional hazards regression. In addition, covariates were identified on the basis of clinical plausibility and significant association ($P < .05$) in univariate analysis. To assess the effects of deaths on the estimate of preoperative TFLBs on risk of TAES, sensitivity analyses and competing risk regression were performed. The multivariable competing risk regression was performed, as suggested previously.^{32,33} Statistical calculations were performed using Empower (R) (<http://www.empowerstats.com>; X&Y Solutions Inc, Boston, Mass).

RESULTS

Patients' demographics, clinical features, and dissection characteristics are summarized in Table 1. The mean age of this cohort was 51.2 ± 10.2 years, and the median number of preoperative TFLBs was 7 (range, 0–20). There was no significant difference with respect to demographic and clinical characteristics between group A (preoperative TFLBs ≥ 8) and group B (preoperative TFLBs < 8). In regard to preoperative morphologic characteristics, group A had a higher number of preoperative abdominal false lumen branches than group B (7 [0–9] vs 4 [0–9], $P = .02$). In addition, patent preoperative thoracic false lumens were observed more frequently in group A than in group B (83.9% vs 66.7%, $P = .04$). Although the limited sample size of the study prevented the differences in these parameters from reaching statistical significance, patients in group A were more likely to have a smaller preoperative true

TABLE 1. Patients' demographic and clinical characteristics, preoperative morphologic characteristics, and operative outcomes

Variables	All patients (N = 67)	Group A (preoperative TFLBs $\geq$ 8) (N = 28)	Group B (preoperative TFLBs <8) (N = 39)	P value
Demographics				
Male, % (n)	85.1 (57)	92.9 (26)	79.5 (31)	.17
Age, y	51.2 $\pm$ 10.2	51.0 $\pm$ 10.8	51.3 $\pm$ 9.8	.92
BMI, kg/m ²	27.0 $\pm$ 4.2	27.1 $\pm$ 3.9	27.0 $\pm$ 4.5	.95
Hypertension	92.5 (62)	92.9 (26)	92.3 (36)	.99
Diabetes	1.5 (1)	0 (0)	2.6 (1)	.99
Hyperlipidemia	11.9 (8)	17.9 (5)	7.7 (3)	.26
Carotid atherosclerosis	11.9 (8)	17.9 (5)	7.7 (3)	.26
Coronary artery disease	11.9 (8)	10.7 (3)	12.8 (5)	.99
Smoking	52.2 (35)	57.1 (16)	48.7 (19)	.50
Renal insufficiency	9.0 (6)	10.7 (3)	7.7 (3)	.69
Chronic obstructive pulmonary disease	4.5 (3)	3.6 (1)	5.1 (2)	.99
Phase of aortic dissection, % (n)				
Acute dissection	74.6 (50)	71.4 (20)	76.9 (30)	
Chronic dissection	25.4 (17)	28.6 (8)	23.1 (9)	
Complicated dissection, % (n)	62.7 (42)	57.1 (16)	66.7 (26)	.43
Preoperative morphologic characteristics				
No. of TFLBs	7 (0-20)	11 (8-20)	4 (0-7)	< .01
Maximum aortic diameter	37.4 $\pm$ 5.4	37.5 $\pm$ 5.5	37.3 $\pm$ 5.4	.88
True lumen diameter	17.3 $\pm$ 5.4	15.8 $\pm$ 5.1	18.3 $\pm$ 5.4	.06
False lumen diameter	18.5 $\pm$ 6.4	19.9 $\pm$ 6.6	17.5 $\pm$ 6.1	.14
L/Hi	0.25 $\pm$ 0.05	0.26 $\pm$ 0.04	0.24 $\pm$ 0.05	.06
No. of involved visceral arteries	1 (0-3)	1 (0-2)	1 (0-3)	.34
No. of reentry tears	1 (0-3)	1 (0-3)	1 (1-2)	.15
No. of abdominal false lumen small branches	5 (0-9)	7 (0-9)	4 (0-9)	.02
False lumen status of thoracic aorta, % (n)				.04
Partially thrombosed	23.9 (16)	10.7 (3)	33.3 (13)	
Patent	76.1 (51)	83.9 (25)	66.7 (26)	
False lumen status of abdominal aorta, % (n)				.07
Completely thrombosed	6.0 (4)	0 (0)	10.3 (4)	
Partially thrombosed	14.9 (10)	7.1 (2)	20.5 (8)	
Patent	79.1 (53)	92.9 (26)	69.2 (27)	
Presence fenestration in iliac artery, % (n)				.09
No	47.8 (32)	35.7 (10)	56.4 (22)	
Yes	52.2 (35)	64.3 (18)	43.6 (17)	
Devices implanted				
Stent-graft No., % (n)				1.00
1 stent-graft	95.5 (64)	96.4 (27)	94.9 (37)	
2 stent-grafts	4.5 (3)	3.6 (1)	5.1 (2)	
Use of restrictive bare stent, % (n)	10.4 (7)	10.7 (3)	10.3 (4)	1.00
Additional bare mental stent, % (n)	4.5 (3)	7.1 (2)	2.6 (1)	.57
Length of stent-graft coverage	163.3 $\pm$ 27.9	165.9 $\pm$ 28.1	161.5 $\pm$ 28.0	.53

Values are mean $\pm$ standard deviation, mean (range), unless otherwise noted. *BMI*, Body mass index; *TFLB*, thoracic false lumen branch; *L/Hi*, length of dissected aorta and height index.

lumen diameter (15.8 ± 5.1 vs 18.3 ± 5.4 , $P = .06$), a greater length of dissected aorta and height index (0.26 ± 0.04 vs 0.24 ± 0.05 , $P = .06$), and a higher proportion of patent abdominal false lumens preoperatively (92.9% vs 69.2%, $P = .07$). Other dissection characteristics, such as indications for TEVAR and devices implanted, were largely similar between the 2 groups.

Because more than 20% of all patients (19/86) were excluded because of a lack of essential data, comparative analyses were performed between the included and excluded patients. The results of this analysis revealed that there was no significant difference between the 2 cohorts of patients (Table E1), indicating that the patients excluded for missing data may have been random.

FIGURE 2. Kaplan–Meier analysis of freedom from TAES incidence based on the number of preoperative TFLBs. Group A: TFLBs 8 or greater. Group B: TFLBs less than 8. TAES, Thoracic aortic enlargement along the stent graft.

Six patients experienced TAES during a median imaging follow-up period of 12.2 months (interquartile range, 4.3–26.6 months). All of these patients were in group A. [Figure 2](#) shows the cumulative TAES rates curves for group A and group B. The 12- and 24-month cumulative TAES rates in group A were 18.7% (95% confidence interval [CI], 1.72–50.0) and 26.8% (95% CI, 4.1–58.0), respectively, versus 0% and 0% in group B. The log-rank test showed that the cumulative TAES rate was higher in group A than in group B ($P < .01$). Among the patients who experienced TAES, 2 deaths occurred in the following months. One occurred at 12 months post-TEVAR due to aortoesophageal fistula, and the other occurred at 19 months post-TEVAR due to retrograde type A dissection. Another 2 patients died of cardiac infarction before the occurrence of TAES.

In addition, distal stent-graft–induced new reentry was detected in 7 patients (2 in group A vs 5 in group B, $P = .69$), new reentry in the lower thoracic aorta occurred in 3 patients (0 in group A vs 3 in group B, $P = .26$), and retrograde type A dissection occurred in 3 patients (2 in group A vs 1 in group B, $P = .57$).

The courses of the changes over time in the maximum diameters of the thoracic aorta, true lumen, and false lumen, stratified according to group A and group B, are shown in [Figure 3](#). From preprocedure to 24 months after the procedure, the maximum thoracic aortic diameter remained stable in group A (change, -0.46 ; standard error [SE], 1.25; $P = .71$) but decreased significantly in group B (change, -2.69 ; SE, 0.55; $P < .01$). The overall change in the maximum thoracic aortic diameter from preprocedure to

FIGURE 3. Diameter measurement over time.

12 months after the procedure was significantly greater in group B than in group A (change difference, 2.51; SE, 0.99; $P = .01$), but this change was no longer significant 24 months after the procedure (change difference, 2.18; SE, 1.24; $P = .08$). Each group exhibited a significant increase in true lumen diameter (group A: change, 14.95; SE, 1.40; $P < .01$; group B: change, 14.20; SE, 1.12; $P < .01$) and a significant decrease in false lumen diameter (group A: change, -14.64 ; SE, 2.30; $P < .01$; group B:

TABLE 2. Postoperative false lumen status along the stent-graft-covered segment

	All patients	Group A (preoperative TFLBs ≥ 8)	Group B (Preoperative TFLBs < 8)	P value
Imaging follow-up period, median (IQR) mo (N)	12.2 (4.3-26.6) (67)	11.8 (4.5-27.9) (28)	12.2 (4.3-25.1) (39)	.97
6 $\pm$ 3 mo, % (n/N)				<.01
Partially thrombosed	43.3 (29/67)	67.9 (19/28)	25.6 (10/39)	
Completely thrombosed	56.7 (38/67)	32.1 (9/28)	74.4 (29/39)	
12 $\pm$ 3 mo, % (n/N)				.01
Partially thrombosed	28.9 (13/45)	52.6 (10/19)	11.5 (3/26)	
Completely thrombosed	71.1 (32/45)	47.4 (9/19)	88.5 (23/26)	
24 $\pm$ 6 mo, % (n/N)				.03
Partially thrombosed	32.0 (8/25)	60.0 (6/10)	13.3 (2/15)	
Completely thrombosed	68.0 (17/25)	40.0 (4/10)	86.7 (13/15)	

TFLB, Thoracic false lumen branch; IQR, interquartile range.

change, -16.23 ; SE, 1.45; $P < .01$) from preprocedure to 24 months after the procedure. The overall change in true lumen diameter was not significantly different between group A and group B, whether from preprocedure to 12 months after the procedure (change difference, -0.51 ; SE, 1.42; $P = .72$) or from preprocedure to 24 months after the procedure (change difference, 0.76 ; SE, 1.78; $P = .67$). The overall change in false lumen diameter was significantly different between group A and group B from preprocedure to 12 months after the procedure (change difference, 3.10 ; SE, 1.45; $P = .03$); however, this trend was no longer significant 24 months after the procedure (change difference, 1.58 ; SE, 1.82; $P = .39$).

The postoperative false lumen status along the stent-graft-covered segment at each follow-up time point is shown in Table 2. Complete thrombosis of the false lumen along the stent-graft-covered segment occurred in 56.7% of all patients at 6 months after the procedure, 71.1% at 12 months, and 68.0% at 24 months. Partial thrombosis of the false lumen occurred more frequently in group A than in group B at each follow-up time point (6 months: 67.9% vs 25.6%, $P < .01$; 12 months: 52.6% vs 11.5%, $P = .01$; 24 months: 60.0% vs 13.3%, $P = .03$). Furthermore, patent TFLBs delivering retrograde false lumen flow were observed in all patients with partial thrombosis in the false lumen postoperatively.

The univariate Cox regression analyses revealed that no variables were associated with TAES with a P value less

than .05, except for preoperative TFLBs, for which the hazard ratio (HR) was 1.23 (95% CI, 1.05-1.45), as listed in Table E2. As shown in Table 3, preoperative TFLBs were independently associated with TAES after TEVAR (HR [for 1 increase], 3.22; 95% CI, 1.22-8.51) after adjustment for gender, hyperlipidemia, and 3 preoperative morphologic variables, including the true lumen diameter, number of involved visceral arteries, and number of abdominal false lumen branches (Table 3, model 2). Further adjustment for the presence of distal stent-graft-induced new reentry during the follow-up period slightly attenuated the association between preoperative TFLBs and TAES (HR [for 1 increase], 2.92; 95% CI, 1.06-8.01).

To assess the potential bias caused by the 2 deaths before the occurrence of TAES, we performed sensitivity analyses by assuming that the 2 patients who died underwent TAES, as well as competing risk regressions. After adjustment for the aforementioned covariates, the HR was 3.04 (95% CI, 1.14-8.1) in the final Cox regression model. In the final competing risk regression model, the HR was 1.72, although the outcome did not reach the statistical significance. These results revealed that the 2 deaths did not materially affect the association between preoperative TFLBs and TAES.

DISCUSSION

For DeBakey III aortic dissections, the long-term goal of endovascular treatment is to inhibit late dilation of the aorta

TABLE 3. Hazard ratios (95% confidence intervals) for the association of preoperative thoracic false lumen branches with risk of thoracic aortic enlargement along the stent graft

	HR (95% CI)		
	Model 1: nonadjusted	Model 2: adjusted for baseline covariates*	Model 3: model 2 plus distal SINE†
Preoperative TFLBs (for 1 increase)	1.23 (1.05-1.45)	3.22 (1.22-8.51)	2.92 (1.06-8.01)

HR, Hazard ratio; CI, confidence interval; SINE, stent-graft-induced new reentry; TFLB, thoracic false lumen branch. *Adjusted for gender, hyperlipidemia, preoperative true lumen diameter, preoperative involved visceral arteries, and preoperative abdominal false lumen branches. †Adjusted for variables in model 1 and distal SINE.

by promoting aortic remodeling.²² Although the most prominent aortic remodeling mainly occurs in the stent-graft-covered segment as opposed to the unstented distal thoracic aorta and the abdominal aorta, several patients have still had enlargement of the stent-graft-covered segment.¹⁰⁻¹³ Our analyses demonstrated that patients with more patent preoperative TFLBs were less likely to develop aortic remodeling than patients with fewer patent preoperative TFLBs, and they potentially had worse clinical outcomes than their counterparts. Preoperative TFLBs are a predictor of the TAES in DeBakey IIIb aortic dissection after TEVAR. After the covariates were held constant, the risk of TAES increased 2.92-fold with a per 1 increase in preoperative TFLBs.

As previously reported, the morphologic characteristics of aortic remodeling include expansion of the true lumen and regression and complete thrombosis of the false lumen.^{4,5,8,34,35} In the current study, the cumulative incidence of TAES was significantly higher among the patients in group A than group B. This result was consistent with the trend in the change in size of the entire aortic lumen: The maximum thoracic aortic diameter decreased significantly over time in group B, but not in group A.

Our results confirmed that the maximum diameters of the thoracic aorta and false lumen tended to decrease more significantly over time in group B than in group A, especially between preprocedure and 12 months after the procedure. The lack of a significant difference in the maximum aortic diameter and false lumen between group A and group B between preprocedure and 24 months after the procedure is probably related to the small number of patients in our series at 24 months after the procedure. Furthermore, by analyzing the changes in size in the true lumen and false lumen between the 2 groups, we could attribute the difference in the maximum aortic diameter changes to the difference in the false lumen diameter changes (Figure 3). These findings suggest that TFLBs can affect the regression of the thoracic aortic false lumen of the stent-graft-covered segment. In addition, patients with more preoperative TFLBs are less likely to benefit from standard TEVAR than patients with fewer preoperative TFLBs.

In our study, complete false lumen thrombosis was more evident in group B than in group A at multiple follow-up time points. As previously reported, persistent perfusion of the false lumen, which hampers complete thrombosis, was associated with aortic dilatation.^{5,34,36} According to our observations, TFLBs functioned as an outflow tract for the perfusion of the stent-graft-covered thoracic aortic false lumen (Video 1). These results further suggest that TFLBs, as outflow tracts of the thoracic false lumen that maintain persistent false lumen perfusion, have a negative impact on the thrombogenic environment.

VIDEO 1. Intraoperative angiography showed TFLBs still played a role as the outflow tract to lead to persistent thoracic false lumen bloodstream after sealing the primary entry in TEVAR. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(17\)31913-X/fulltext](http://www.jtcvsonline.org/article/S0022-5223(17)31913-X/fulltext).

The rationale that complete thrombosis mainly occurs in the stent-graft-covered segment is based on sealing the proximal entry tear, reapproximating the flap to the aortic wall, and restricting motion of intimal flap throughout the cardiac cycle.^{1,37-39} However, as shown in the schematic drawing (Figure 4), the complete thrombosis of the stent-graft-covered false lumen is hampered by the presence of blood flow, which is maintained by outflow of patent TFLBs, including intercostal and bronchial arteries involved in dissection. In addition, these uncovered multiple downstream entry tears, which are common in DeBakey IIIb aortic dissections, provide adequate inflow for thoracic false lumen. Therefore, 1-stage transcatheter arterial embolization of selective TFLBs with microcoils is a potential approach to facilitate thoracic aortic false lumen remodeling of the stent-graft-covered segment.

In the current study, the preoperative TFLBs of the entire thoracic aortic segment, rather than the corresponding segment along the stent graft, were counted as parameters for analysis, based on the anatomic characteristics of the TFLBs and the patency of the blood flow pathway. First, the bloodstream in the false lumen of the stent-graft-covered segment was the result of the cumulative effects of the TFLBs as the outflow tracts of the false lumen of the thoracic aorta. The results of this analysis are supported by the results of the multivariate Cox regression, which demonstrated that the incidence of TAES increased

FIGURE 4. Schematic drawing demonstrates that the TFLBs as the outflow tract have an effect on perfusion of thoracic aortic false lumen along the stent graft after covering the proximal entry.

significantly with increases in preoperative TFLBs. Anatomically, the thoracic aortic branch arteries are small in diameter but large in quantity. As Poiseuille's law shows, the volumetric flow rate through a vessel is proportional to the fourth power of the vessel radius when the pressure drop and vessel length are constant. Thus, an increase in the number of TFLBs results in an exponential increase in the blood flow rate. Second, the thoracic aortic branch vessels, especially the posterior intercostal arteries, are continuously distributed along the descending thoracic aorta. The TFLBs distal to the stent graft play a role not only in increasing the blood flow rate in the thoracic aortic false lumen but also in maintaining the patency of the blood flow pathway. These findings also indicate that post-TEVAR thoracic aortic false lumen perfusion can be prevented by obstructing the false lumen, even in the portion of the aorta distal to the stent graft. A similar treatment strategy, known as the "cork in the bottleneck," was applied to treat chronic aortic dissection in 2003 by Loubert and colleagues.⁴⁰

Study Limitations

This study had several limitations that must be considered when interpreting the data. First, this was a single-center retrospective observational study with a relatively small number of patients. Second, deaths before the TAES observed may lead to potential bias. Although all results in sensitivity analyses, as well as competing risk regressions, demonstrated that the 2 deaths did not bias the results significantly, studies in a larger size are still helpful to further verify the study results. Third, the diametric measurement at a fixed anatomic level may not

remain the most clinically relevant because it cannot provide the threshold for a secondary intervention directly. However, it is a more sensitive way to quantify structural changes in the aorta over time. Fourth, the duration of the imaging follow-up period may be short for evaluation of aortic enlargement. However, previous observational studies have confirmed that the risk of false lumen dilation was higher in patients with partial, rather than complete, thrombosis of the false lumen.^{8-10,14,34,41} Moreover, as shown in the current study, aortic dissections with more preoperative TFLBs were more inclined to develop partially thrombosed false lumens over time than dissections with fewer preoperative TFLBs. Therefore, extending follow-up times would have likely further strengthened the observed association between TFLBs and TAES. Fifth, our hypothesis that TFLBs result in retrograde flow and partial thrombosis of the false lumen was based on persistent patent postoperative TFLBs. The number of preoperative TFLBs is not equivalent to postoperative TFLBs because some TFLBs may close spontaneously after successful endografting (Figure 1, D). We cannot accurately quantify the numbers of patent postoperative TFLBs even when using delayed contrast thin-cut imaging because the postoperative false lumen thrombosis impeded rapid distribution of contrast material in thoracic false lumen, leading to unsatisfied opacification of thoracic small branches on CTA images. The predictive value of preoperative TFLBs can be explained by that patients with more preoperative TFLBs also had more postoperative TFLBs. Future studies using intravascular ultrasonography and 4-dimensional phase contrast magnetic resonance imaging, which allow the hemodynamic characteristics of the aortic remodeling process to be visualized and quantified, will better elucidate the association between TFLBs and TAES after TEVAR.⁴²

CONCLUSIONS

Preoperative TFLBs are a morphologic predictor of TAES in DeBakey IIIb aortic dissection after TEVAR. Thoracic aortic false lumen remodeling of the stent-graft-covered segment consisting of diameter regression and complete thrombosis occurs more often in DeBakey IIIb aortic dissection with preoperative TFLBs less than 8 compared with preoperative TFLBs 8 or greater. Our findings may facilitate the identification of patients at higher risk of TAES using imaging scan before performing TEVAR.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: aortic dissection, TEVAR, aortic remodeling, thoracic false lumen branches

FIGURE E1. Receiver operating characteristic curve for TAES and preoperative TFLBs. The optimal cutoff value of preoperative TFLBs for prediction of TAES during follow-up was 8 with 100.0% sensitivity and 69.4% specificity. The area under the curve was 0.864. *NNE*, Nearest neighbor estimation; *AUC*, area under the curve.

TABLE E1. Comparison of the included and excluded patients' baseline characteristics

Variables	Included patients N = 67	Excluded patients N = 19	P value
Demographics			
Female, % (n)	14.9 (10)	26.3 (5)	.25
Age, y	51.2 ± 10.2	55.2 ± 9.7	.11
BMI, kg/m ²	27.0 ± 4.2	25.5 ± 4.4	.18
Hypertension	92.5 (62)	89.5 (17)	.65
Diabetes	1.5 (1)	0 (0)	.99
Hyperlipidemia	11.9 (8)	5.3 (1)	.68
Carotid atherosclerosis	11.9 (8)	10.5 (2)	.99
Coronary artery disease	11.9 (8)	10.5 (2)	.99
Smoking	52.2 (35)	52.6 (10)	.99
Renal insufficiency	9.0 (6)	5.63 (1)	.99
Chronic obstructive pulmonary disease	4.5 (3)	5.3 (1)	.99
Dissection characteristics			
Acute dissection, % (n)	74.6 (50)	89.5 (17)	.22
Complicated dissection, % (n)	62.7 (42)	68.4 (13)	.65
Preoperative morphologic characteristics			
Maximum aortic diameter, (n)	37.4 ± 5.4 (67)	37.2 ± 6.5 (18)	.92
True lumen diameter, (n)	17.3 ± 5.4 (67)	17.7 ± 4.1 (18)	.74
False lumen diameter, (n)	18.5 ± 6.4 (67)	18.0 ± 5.9 (18)	.75
L/Hi, (n)	0.25 ± 0.05 (67)	0.25 ± 0.04 (18)	.76
No. of TFLBs (n)	7 (0-20) (67)	6 (0-14) (18)	.40
No. of involved visceral arteries (n)	1 (0, 3) (67)	0 (0, 2) (18)	.43
No. of abdominal false lumen branches (n)	5 (0-9) (67)	5 (0-10) (18)	.65
False lumen status of thoracic aorta, % (n/N)			.76
Partially thrombosed	23.9 (16/67)	27.8 (5/18)	
Patent	76.1 (51/67)	72.2 (13/18)	
False lumen status of abdominal aorta, % (n/N)			.71
Completely thrombosed	6.0 (4/67)	11.1 (2/18)	
Partially thrombosed	14.9 (10/67)	16.7 (3/18)	
Patent	79.1 (53/67)	72.2 (13/18)	
Fenestration in iliac artery, % (n/N)			.60
No	47.8 (32/67)	55.6 (10/18)	
Yes	52.2 (35/67)	44.4 (8/18)	
Devices implanted, % (n)			
Stent-graft No.			1.00
1 stent-graft	95.5 (64)	94.7 (18)	
2 stent-grafts	4.5 (3)	5.3 (1)	
Use of restrictive bare stent	10.4 (7)	21.1 (4)	.25
Additional bare mental stent	4.5 (3)	0 (0)	1.00

Values are mean ± standard deviation, mean (range), unless otherwise noted. BMI, Body mass index; L/Hi, length of dissected aorta and height index; TFLB, thoracic false lumen branch.

TABLE E2. Univariable Cox regression analyses for associations between each variable and thoracic aortic enlargement along the stent grafts

	HR (95% CI)	P value
Female (vs male)	1.06 (0.12-9.12)	.95
Age (for 1-y increase)	0.98 (0.91-1.06)	.58
BMI (for 1 increase)	1.02 (0.85-1.21)	.86
Hyperlipidemia	1.22 (0.14-10.51)	.85
Smoke	0.42 (0.08-2.31)	.32
Acute dissection (vs chronic)	0.33 (0.07-1.64)	.17
Complicated dissection (vs uncomplicated)	1.25 (0.23-6.82)	.80
Maximum aortic diameter (for 1-mm increase)	1.00 (0.85-1.16)	.96
True lumen diameter (for 1-mm increase)	1.09 (0.93-1.27)	.29
False lumen diameter (for 1-mm increase)	0.94 (0.82-1.08)	.37
L/Hi (for 1 increase)	6.26 (0.79-49.78)	.09
Preoperative TFLBs (for 1 increase)	1.23 (1.05-1.45)	.01
Preoperative abdominal false lumen branches (for 1 increase)	1.03 (0.79-1.34)	.83
Involved visceral arteries (for 1 increase)	0.35 (0.07-1.70)	.19
Fenestration in iliac artery (yes vs no)	1.67 (0.31-9.14)	.55
The length of stent-graft coverage (for 1-mm increase)	0.99 (0.95-1.02)	.52
Distal SINE (yes vs no)	3.19 (0.57-17.80)	.19

HR, Hazard ratio; CI, confidence interval; BMI, body mass index; L/Hi, length of dissected aorta and height index; TFLB, thoracic false lumen branches; SINE, stent-graft-induced new reentry.