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Article

Predictive Value of the Preoperative Descending Aortic Tortuosity Index for Endoleak After Thoracic Endovascular Aortic Repair in Acute Type B Aortic Dissection

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Abstract

Background: Endoleak is one of the most common adverse events after thoracic endovascular aortic repair (TEVAR) in patients with acute complicated Stanford type B aortic dissection (cTBAD). Interestingly, endoleak may affect aortic remodeling and increase the risk of reintervention. Previous studies on postoperative endoleak have mainly focused on local anatomical parameters of the landing zone. In contrast, the predictive value of overall descending aortic morphology, particularly the descending aortic tortuosity index (DATI), has not been systematically evaluated. Therefore, this study aimed to assess the predictive value of preoperative DATI for postoperative endoleaks after TEVAR in patients with acute cTBAD. **Methods:** This single-center retrospective observational study included 221 patients with acute cTBAD who underwent TEVAR at our hospital between January 2021 and December 2025. DATI and other aortic morphological parameters were measured using centerline reconstruction based on preoperative aortic computed tomography angiography (CTA). Patients were divided into an endoleak group and a non-endoleak group according to the occurrence of persistent or new-onset postoperative endoleak during follow-up. Baseline characteristics, imaging parameters, perioperative data, endoleak types, false lumen perfusion, and false lumen thrombosis status were compared between the two groups. Univariable and multivariable logistic regression analyses were used to evaluate factors associated with postoperative endoleak. Receiver operating characteristic (ROC) curve analysis was used to assess the discriminatory performance of DATI, and Kaplan–Meier curves and Cox proportional hazards regression were used to evaluate the association between DATI and time to endoleak onset. **Results:** The median duration of postoperative imaging follow-up was 12 (6–18) months. During follow-up, 38 of 221 patients (17.2%) experienced persistent or new-onset postoperative endoleak. Among these patients, 22 had type IA endoleak (10.0% of the overall cohort and 57.9% of endoleak events), eight had type IB endoleak (3.6% and 21.1%), five had type II endoleak (2.3% and 13.2%), and three had type III endoleak (1.4% and 7.9%). A total of 28 endoleaks (73.7%) were detected on the first postoperative CTA, and 10 (26.3%) were first identified on subsequent follow-up CTA. DATI was significantly higher in the endoleak group than in the non-endoleak group (26.1 ± 8.5% vs 18.3 ± 7.2%; $p < 0.001$). Multivariable logistic regression showed that DATI (odds ratio (OR) = 1.09; 95% confidence interval (CI), 1.04–1.14; $p < 0.001$), proximal landing zone length (OR = 0.91; 95% CI, 0.85–0.98; $p = 0.008$), and immediate intraoperative endoleak (OR = 2.85; 95% CI, 1.08–7.52; $p = 0.034$) were independently associated with postoperative endoleak. ROC curve analysis showed that the area under the receiver operating characteristic (AUROC) curve of DATI for predicting postoperative endoleak was 0.783 (95% CI, 0.710–0.856). The optimal cutoff value was 22.5%, with a sensitivity of 71.1% and a specificity of 74.3%. Kaplan–Meier analysis showed that patients with DATI ≥22.5% had lower endoleak-free survival than those with DATI <22.5% (log-rank $p < 0.001$). In the adjusted Cox model, DATI ≥22.5% remained associated with the occurrence of endoleak (adjusted hazard ratio (HR) = 4.38; 95% CI, 2.08–9.21; $p < 0.001$). **Conclusion:** In this single-center retrospective study, preoperative DATI may be independently associated with persistent or new-onset endoleak after TEVAR in patients with acute cTBAD and may have moderate discriminatory ability. A DATI ≥22.5% may indicate a higher risk of endoleak during follow-up. Incorporating DATI into preoperative morphological assessment may serve as an adjunct to risk stratification and procedural planning, although this cutoff value requires external validation.

Keywords: dissection; thoracic aorta; endoleak; endovascular aneurysm repair; predictive value of tests; computed tomography angiography

1. Introduction

Acute Stanford type B aortic dissection (TBAD) is a sudden-onset, rapidly progressive, and life-threatening aortic emergency. In complicated cases, early mortality is markedly increased because of concomitant aortic rupture or malperfusion syndrome [1]. Thoracic endovascular aortic repair (TEVAR) is minimally invasive and has technical advantages for rapid exclusion of the primary entry tear; therefore, it has become the preferred treatment strategy for acute complicated TBAD. Multiple studies have shown that TEVAR can effectively improve short- and mid-term outcomes [2]. However, endoleak, one of the most common procedure-related complications after TEVAR, not only indicates persistent false lumen pressurization and adverse aortic remodeling but may also lead to aortic dilatation and even rupture in severe cases. Thus, endoleak is one of the main drivers of postoperative reintervention [3]. Previous studies have shown that unfavorable proximal landing zone anatomy, such as a short landing zone or marked angulation, stent-graft malapposition, and intraoperative technical factors are closely associated with the occurrence of endoleak [4]. Nevertheless, most of these studies have focused on local anatomical parameters, and systematic quantitative assessment of the overall morphology of the descending aorta remains limited.

Descending aortic tortuosity is a relatively common anatomical feature in patients with aortic dissection. Increased tortuosity may impede passage of the stent-graft delivery system and cause uneven apposition after deployment, thereby increasing the risk of proximal or distal sealing failure [5]. The tortuosity index is an objective quantitative indicator of vascular curvature and has been shown to be associated with postoperative endoleak and device-related adverse events in the field of endovascular abdominal aortic aneurysm repair [6,7]. However, its predictive value in TEVAR for acute TBAD has not been fully investigated. Therefore, in this study, the descending aortic tortuosity index (DATI) was measured on preoperative computed tomography angiography (CTA) to clarify its independent predictive value for endoleak after TEVAR and to provide a more comprehensive morphological reference for preoperative risk stratification and procedural planning.

2. Materials and Methods

2.1 Study Population

This was a single-center retrospective observational study. Clinical data were collected from patients with acute complicated Stanford type B aortic dissection (cTBAD) who underwent thoracic endovascular aortic repair (TEVAR) at our hospital between January 2021 and December 2025. The acute phase was defined as an interval of ≤14 days from symptom onset to surgery. Complicated dissection was diagnosed mainly according to the 2022 Society for Vascular Surgery (SVS) and Society of Thoracic Surgeons (STS) reporting standards for type B aortic dissection [8] and was defined as the presence of aortic rupture or impending rupture and/or malperfusion syndrome, including visceral, renal, spinal cord, or limb malperfusion. Refractory pain, refractory hypertension, early aortic enlargement, and adverse imaging features were recorded separately as high-risk features but were not used as inclusion criteria for defining complicated cases in this study. The indication for TEVAR was determined comprehensively according to the patient's clinical presentation, imaging findings, current standards for the management of aortic disease, and the treatment strategy at our institution. The study protocol was approved by the institutional ethics committee, and the requirement for informed consent was waived because of the retrospective observational design.

Inclusion criteria:

(1) Age ≥18 years;

(2) Stanford type B aortic dissection confirmed by aortic computed tomography angiography (CTA);

(3) Meeting the diagnostic criteria for acute complicated type B aortic dissection, namely the presence of aortic rupture/impending rupture and/or malperfusion syndrome;

(4) Symptom-to-surgery interval ≤14 days;

(5) Treatment with TEVAR;

(6) Complete preoperative aortic CTA data adequate for morphological measurements and at least one postoperative CTA examination available for outcome assessment.

Exclusion criteria:

(1) Concomitant Stanford type A aortic dissection;

(2) Aortic arch disease requiring concomitant open total arch replacement or hybrid surgery;

(3) Previous open aortic surgery or endovascular aortic repair;

(4) Traumatic or iatrogenic aortic dissection;

(5) Confirmed hereditary connective tissue disease, such as Marfan syndrome or Loeys-Dietz syndrome;

(6) Poor preoperative CTA image quality precluding morphological measurement of the descending aorta;

(7) No postoperative imaging follow-up is available to assess the endoleak outcome.

2.2 Clinical Data Collection

The following data were collected from the electronic medical record system:

(1) General demographic characteristics: sex, age, and body mass index (BMI);

(2) Comorbidities and risk factors: history of hypertension, diabetes mellitus, coronary artery disease, cerebrovascular disease, chronic renal insufficiency, chronic obstructive pulmonary disease, and smoking history;

(3) Disease-related data at presentation: symptom-to-surgery interval; category of complicated presentation [rupture/impending rupture, malperfusion, or combined presentation (both rupture/impending rupture and malperfusion)]; and the presence of high-risk features, including refractory

pain, refractory hypertension, early aortic enlargement, and adverse imaging features;

(4) Dissection anatomy: the extent of dissection was classified as limited to the thoracic aorta or involving the thoracoabdominal aorta; iliac artery involvement and distal re-entry tears were recorded separately. For distal residual dissection after proximal TEVAR, intensive medical therapy and sequential CTA follow-up were routinely adopted. When persistent dynamic malperfusion, severe true lumen compression, or insufficient distal true lumen expansion was present, a distal bare stent was selectively placed distal to the TEVAR segment for provisional extension to induce complete attachment (PETTICOAT)-like support;

(5) Intraoperative data: proximal landing zone location, coverage of the left subclavian artery (LSA), LSA reconstruction, use of adjunctive chimney or fenestration techniques, stent-graft oversizing rate, immediate intraoperative angiographic endoleak, distal bare-stent/PETTICOAT-like support distal to the TEVAR segment, stent-assisted balloon-induced intimal disruption and relamination in aortic dissection (STABILISE)-like balloon-assisted intimal flap stabilization, Candy-Plug false lumen occlusion, and concomitant intraoperative management;

(6) Postoperative data: intensive care unit (ICU) stay, hospital stay, perioperative complications, timing of the first postoperative CTA follow-up, and aortic-related reinterventions during follow-up.

2.3 Imaging Measurements

All patients underwent preoperative whole-aorta CTA. Scanning was performed using a Brilliance 64-channel multidetector-row computed tomography scanner (system version 4.1.10; Philips Medical Systems Nederland B.V., Best, North Brabant, the Netherlands), covering the region from the thoracic inlet to the femoral artery bifurcations. Iohexol (350 mg I/mL, 100 mL:35 g(I); National Medical Products Administration approval No. H20203257; Shanghai Starry Pharmaceutical Co., Ltd., Shanghai, China) or iopamidol (370 mg I/mL, 100 mL:37 g(I); National Medical Products Administration approval No. H20203203; Shanghai Starry Pharmaceutical Co., Ltd., Shanghai, China) was used as the contrast agent and was injected at a rate of 4.0–5.0 mL/s, with a total volume of 80–100 mL. Bolus-tracking technology was used, with a trigger threshold of 100–150 Hounsfield units (HU). Slice thickness was ≤1.0 mm, and the reconstruction interval was ≤0.5 mm. All morphological measurements were performed using the most recent qualified CTA images obtained before TEVAR. Imaging data were imported into a three-dimensional post-processing workstation, such as 3mensio Vascular or Aquarius iNtuition (version 4.4.13; TeraRecon, Inc., Durham, NC, USA). All morphological parameters were based on centerline reconstruction and were measured on short-axis planes perpendicular to the aortic centerline.

The measurement range for DATI was defined as follows: proximally, the level immediately distal to the LSA origin; distally, the level of the celiac trunk origin. The actual curved path length along the aortic centerline was measured and recorded as the centerline length (CL). The straight-line distance between the two endpoints was measured and recorded as the straight-line distance (SL). DATI was calculated as follows:

$$DATI = (CL - SL) / SL \times 100\%.$$

A higher DATI indicates greater tortuosity of the descending aorta.

The following aortic morphological parameters were also measured:

(1) Proximal landing zone diameter: within the planned proximal landing zone, the maximum outer-wall-to-outer-wall diameter was measured on a short-axis plane perpendicular to the centerline in an aortic segment without an obvious primary entry tear and with relatively stable morphology. If both proximal and distal portions of the landing zone were suitable for measurement, the average of the two values was used;

(2) Proximal landing zone length;

(3) Distance from the proximal primary entry tear to the LSA origin;

(4) Aortic arch angle: defined as the angle formed by the highest point of the aortic arch and the intersections of the ascending and descending aortic centerlines;

(5) Proximal landing zone angulation: defined as the angle between the landing zone centerline and the distal thoracic aortic centerline;

(6) Extent of dissection: involvement of the abdominal aorta and iliac arteries;

(7) Maximum false lumen diameter: measured on a short-axis plane perpendicular to the centerline at the most severely involved segment of the descending thoracic aorta;

(8) Minimum true lumen diameter: measured on a short-axis plane perpendicular to the centerline at the most severely involved segment of the descending thoracic aorta;

(9) Location and size of the primary entry tear.

The distal landing zone was defined as the true lumen segment immediately adjacent to the distal edge of the thoracic aortic stent-graft. Based on centerline-reconstructed CTA, distal landing zone length was measured as the centerline distance from the distal edge of the stent-graft to the nearest major distal re-entry tear. If no major distal re-entry tear was observed in the thoracic aortic segment, the distance was measured to the level of the celiac trunk. An effective distal landing zone was defined as a segment length ≥20 mm, good stent-graft apposition, and no severe true lumen collapse. Aortic coverage length was defined as the centerline length between the proximal and distal edges of all thoracic aortic stent-graft components.

2.4 Procedure

All TEVAR procedures were performed in a hybrid operating room under general anesthesia or local anesthesia with sedation. Access was established by surgical cut-down or percutaneous puncture of the femoral artery. The procedure was performed under digital subtraction angiography (DSA) guidance, with transesophageal echocardiography (TEE) monitoring when necessary. The stent-graft system was advanced to the planned position and deployed to seal the proximal primary entry tear, promote true lumen reconstruction, and improve distal perfusion. The proximal landing zone was preferentially selected distal to the LSA in an aortic segment with relatively regular morphology, no obvious entry tear, and limited dissection involvement. An effective landing zone length of at least 15 mm was generally required.

The stent-graft diameter was selected according to the total aortic outer diameter (outer wall to outer wall) measured at the proximal landing zone on a short-axis plane perpendicular to the centerline and was usually oversized by 0%–10% relative to the mean diameter. If the proximal landing zone was obviously involved by dissection, stent-graft sizing was preferentially determined according to the outer diameter of the nearest relatively normal proximal aortic segment. In this study, the stent-graft oversizing rate was defined as follows:

(Nominal stent-graft diameter − mean outer diameter of the proximal landing zone aorta) / mean outer diameter of the proximal landing zone aorta × 100%.

When LSA coverage was required, the need for LSA reconstruction (bypass or transposition) was assessed preoperatively according to vertebrobasilar circulation, completeness of the circle of Willis, and perfusion of the left upper limb and/or coronary artery bypass grafts. Immediately after stent-graft deployment, DSA was performed to assess stent-graft position, expansion, and the presence of endoleak. If obvious endoleak, malapposition, or unsatisfactory positioning was detected intraoperatively, balloon post-dilation, additional stent-graft implantation, or branch reconstruction was performed when feasible.

For distal residual dissection after proximal TEVAR, intensive medical therapy and sequential CTA follow-up were routinely adopted. When persistent dynamic malperfusion, severe true lumen compression, or insufficient distal true lumen expansion was present, a distal bare stent was selectively placed distal to the TEVAR segment for PETTICOAT-like support. STABILISE-like balloon-assisted intimal flap stabilization was used only in highly selected cases. In this acute cTBAD cohort, no patient underwent Candy-Plug false lumen occlusion during the initial procedure.

2.5 Definition and Classification of Endoleak

Endoleak was defined as persistent contrast perfusion outside the stent-graft lumen into the aortic false lumen on imaging after TEVAR. Endoleaks were classified according to their source: type I endoleak (proximal type IA or distal type IB) resulted from incomplete sealing between the stent-graft and the aortic wall; type II endoleak resulted from retrograde perfusion of the false lumen through branch arteries; and type III endoleak resulted from incomplete connection between stent-graft components or damage to the stent-graft material or structure.

In this study, immediate intraoperative endoleak was recorded separately as a perioperative technical variable and was not directly included in the definition of the primary outcome. The primary outcome was defined as persistent endoleak or new-onset endoleak confirmed by the first postoperative CTA or subsequent follow-up CTA. If an immediate intraoperative endoleak disappeared on the first postoperative CTA after concomitant intraoperative management, it was not counted as a primary outcome event.

In addition to treating any persistent or new-onset postoperative endoleak as the primary composite outcome, exploratory subgroup analyses were performed according to endoleak type. Because type IA and type IB endoleaks reflect proximal and distal sealing failure, respectively, they were analyzed separately. Because the number of type II and type III endoleak events was small, they were described using descriptive statistics only and were combined as type II/III endoleak in the exploratory analysis. False lumen perfusion was defined as contrast enhancement outside the stent-graft lumen or within the false lumen of the residual dissection on postoperative CTA. False lumen status was categorized as complete thrombosis, partial thrombosis, or persistent patency/perfusion and was assessed separately in the stent-graft-covered thoracic aortic segment and the residual thoracoabdominal dissected segment.

2.6 Postoperative Follow-Up

During hospitalization, the first postoperative CTA was routinely performed approximately 5–10 days after surgery. After discharge, follow-up was scheduled at 1, 3, 6, and 12 months postoperatively and annually thereafter. At each follow-up visit, the occurrence of aortic-related adverse events was recorded. Aortic-related adverse events included endoleak, stent-graft migration, new entry tear or retrograde dissection, aortic enlargement (maximum diameter increase >5 mm/year), aortic-related reintervention, and aortic-related death.

The final follow-up cutoff date for this study was December 31, 2025, and the study database was locked on the same date. The minimum imaging follow-up requirement for primary outcome assessment was at least one postoperative CTA examination. The follow-up endpoint was defined as the earliest of the following: the date of the last completed CTA follow-up, the date of occurrence of the primary outcome event, or the date of aortic-related death.

According to the occurrence of persistent or new-onset postoperative endoleak during follow-up, the 221

patients were divided into an endoleak group and a non-endoleak group. Baseline characteristics, aortic morphological parameters (including DATI), and procedure-related data were compared between the two groups. Immediate intraoperative endoleak was included in the analysis only as a perioperative variable and was not used as a grouping criterion.

2.7 Statistical Analysis

All CTA images were independently reviewed by two physicians experienced in vascular imaging under a blinded assessment protocol. The reviewers were blinded to patients' clinical information, procedural outcomes, follow-up outcomes, and each other's assessments. Discrepancies between the two reviewers were resolved by consensus, and a third senior physician was consulted for final adjudication when necessary. Interobserver agreement was high, with an intraclass correlation coefficient of 0.93 for DATI measurement, 0.90 for proximal landing zone length, 0.91 for proximal landing zone diameter, and 0.88 for primary entry tear size. For categorical CTA findings, Cohen's kappa values were 0.87 for postoperative endoleak identification, 0.84 for endoleak type classification, 0.86 for false lumen perfusion, and 0.82 for false lumen thrombosis status. The final consensus or adjudicated imaging findings were used for statistical analysis.

Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA) and R version 4.3.0 (R Foundation for Statistical Computing, Vienna, Austria). The normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed variables are presented as mean ± standard deviation (SD) and were compared between groups using the independent-samples t test; non-normally distributed variables are presented as median (interquartile range, IQR) and were compared between groups using the Mann–Whitney U test. Categorical variables are presented as counts (percentages) and were compared between groups using the Pearson χ^2 test; Fisher's exact test was used when the expected frequency was small or the assumptions for the χ^2 test were not met. Test statistics included t, Z, χ^2, or Wald χ^2. All tests were two-sided, and $p < 0.05$ was considered statistically significant.

Univariable logistic regression was first used to screen candidate factors associated with postoperative endoleak. Variables with clinical relevance and $p < 0.10$ in univariable analysis were entered into the multiple logistic regression model. To avoid model overfitting, the number of variables included in the final multiple logistic regression model was controlled according to the number of positive outcome events, ensuring an events-per-variable (EPV) ratio $\geq$10. Variance inflation factors (VIFs) were used to evaluate multicollinearity among candidate variables. In the main analysis, DATI was included in the regression model as a continuous variable, and the results are expressed as odds ratios (ORs) and 95% confidence intervals (CIs). Receiver operating characteristic (ROC) curve analysis was further used to evaluate the discriminatory performance of DATI for postoperative endoleak, and the area under the receiver operating characteristic curve (AUC), sensitivity, and specificity were calculated. The optimal cutoff value was determined using the Youden index. Dichotomized analysis based on this cutoff value was performed only as an exploratory stratified analysis. The Hosmer–Lemeshow test was used to assess model goodness of fit.

Exploratory subgroup analyses were further performed for type I endoleak, type IA endoleak, type IB endoleak, and combined type II/III endoleak. Because the number of events for each subtype was limited, Firth penalized likelihood univariable logistic regression was used, and the results were considered hypothesis-generating only. Time to endoleak onset was defined as the interval between the initial TEVAR procedure and the first CTA-confirmed persistent or new-onset endoleak. Patients without endoleak were censored at the last available CTA follow-up. Endoleak-free survival was estimated using the Kaplan–Meier method, and differences between DATI-stratified groups were compared using the log-rank test. Cox proportional hazards regression was used to analyze the association between DATI and time to endoleak onset, and the proportional hazards assumption was evaluated using the Schoenfeld residual test.

3. Results

3.1 Patient Enrollment Process, General Characteristics, and Postoperative Endoleak Types

A total of 286 patients with Stanford type B aortic dissection who initially underwent TEVAR were screened. Sixty-five patients were excluded for the following reasons: symptom-to-surgery interval >14 days (n = 18), uncomplicated TBAD or only high-risk features without rupture/malperfusion (n = 14), concomitant open total arch replacement or hybrid arch surgery (n = 6), Stanford type A dissection or retrograde type A dissection before inclusion (n = 5), previous open or endovascular aortic repair (n = 7), traumatic/iatrogenic dissection or hereditary connective tissue disease (n = 6), inadequate preoperative CTA quality (n = 4), and no postoperative CTA follow-up (n = 5). Finally, 221 patients were included (**Supplementary Fig. 1**).

Among them, 173 patients (78.3%) were male and 48 (21.7%) were female. The mean age was 53.9 ± 10.8 years, and the mean BMI was 24.9 ± 3.4 kg/m^2. Regarding the category of complicated presentation, 150 patients (67.9%) had malperfusion, 40 (18.1%) had rupture or impending rupture, and 31 (14.0%) had a combined presentation. High-risk features were present in 108 patients (48.9%). The median symptom-to-surgery interval was 4 (2, 7) days. The median duration of postoperative imaging follow-up was 12 (6, 18) months.

Table 1. Comparison of baseline clinical characteristics between the two groups.

Variable	Non-endoleak group (n = 183)	Endoleak group (n = 38)	Statistic	*p* value
Male, n (%)	143 (78.1)	30 (78.9)	$\chi^2 = 0.012$	0.912
Age (years)	53.8 ± 10.7	54.5 ± 11.2	$t = -0.368$	0.713
Body mass index (kg/m^2)	24.8 ± 3.4	25.2 ± 3.1	$t = -0.678$	0.499
History of hypertension, n (%)	148 (80.9)	32 (84.2)	$\chi^2 = 0.225$	0.635
History of diabetes mellitus, n (%)	12 (6.6)	3 (7.9)	-	0.727†
History of coronary artery disease, n (%)	15 (8.2)	4 (10.5)	-	0.749†
History of cerebrovascular disease, n (%)	10 (5.5)	3 (7.9)	-	0.472†
Chronic renal insufficiency, n (%)	8 (4.4)	2 (5.3)	-	0.683†
Chronic obstructive pulmonary disease, n (%)	11 (6.0)	3 (7.9)	-	0.713†
Smoking history, n (%)	79 (43.2)	18 (47.4)	$\chi^2 = 0.228$	0.633
Symptom-to-surgery interval (days)	4 (2, 7)	3 (2, 6)	$Z = 0.872$	0.383
Category of complicated presentation, n (%)			$\chi^2 = 0.473$	0.789
Rupture/impending rupture	32 (17.5)	8 (21.1)		
Malperfusion	126 (68.9)	24 (63.2)		
Combined presentation	25 (13.7)	6 (15.8)		
Presence of high-risk features, n (%)	88 (48.1)	20 (52.6)	$\chi^2 = 0.258$	0.612

Note: Continuous variables are presented as mean ± standard deviation or median (interquartile range), according to distribution; categorical variables are presented as counts (percentages). χ^2 denotes the Pearson χ^2 test statistic; t denotes the independent-samples t test statistic; Z denotes the Mann–Whitney U test statistic; p values are two-sided. † Fisher's exact test. For variables marked with † and with '-' in the statistic column, p values were calculated using Fisher's exact test.

During follow-up, 38 of 221 patients (17.2%) experienced persistent or new-onset postoperative endoleak. Among them, 22 had type IA endoleak (10.0% of the overall cohort and 57.9% of endoleak events), 8 had type IB endoleak (3.6% and 21.1%), 5 had type II endoleak (2.3% and 13.2%), and 3 had type III endoleak (1.4% and 7.9%) (**Supplementary Fig. 2**). Twenty-eight endoleaks (73.7%) were detected on the first postoperative CTA, and 10 (26.3%) were first identified on subsequent follow-up CTA. In addition, during follow-up, 20 patients (9.0%) underwent aortic-related reintervention, 8 (3.6%) had stent-graft migration, 4 (1.8%) developed a new entry tear or retrograde dissection, 10 (4.5%) developed aortic enlargement, and 0 (0.0%) died of aortic-related causes. These aortic-related adverse events could occur in the same patient; therefore, the sum of individual event counts does not equal the total number of patients with events. According to the occurrence of persistent or new-onset postoperative endoleak during follow-up, patients were divided into the endoleak group (n = 38) and the non-endoleak group (n = 183).

3.2 Comparison of Baseline Clinical Characteristics Between the Two Groups

There were no statistically significant differences between the two groups in sex, age, BMI, comorbidities and risk factors, symptom-to-surgery interval, category of complicated presentation, or presence of high-risk features (all $p > 0.05$) (Table 1).

3.3 Comparison of Aortic Morphological Parameters Between the Two Groups

DATI was significantly higher in the endoleak group than in the non-endoleak group ($p < 0.001$). Compared with the non-endoleak group, the endoleak group had a larger proximal landing zone diameter, greater proximal landing zone angulation, larger maximum false lumen diameter, and larger primary entry tear size, whereas proximal landing zone length, the distance from the proximal primary entry tear to the LSA origin, aortic arch angle, and minimum true lumen diameter were smaller (all $p < 0.05$). There were no statistically significant differences between the two groups in dissection extent or distribution of primary entry tear location (all $p > 0.05$) (Table 2).

3.4 Comparison of Procedural and Perioperative Data Between the Two Groups

There were no statistically significant differences between the two groups in proximal landing zone location, LSA coverage, LSA reconstruction rate among patients with LSA coverage, or use of chimney or fenestration techniques (all $p > 0.05$). The stent-graft oversizing rate was higher in the endoleak group than in the non-endoleak group ($p = 0.016$), and the incidence of immediate intraoperative endoleak was also higher in the endoleak group ($p = 0.005$). Among patients with immediate intraoperative endoleak, the concomitant intraoperative management rate did not differ significantly between groups ($p = 1.000$). ICU stay and hospital stay were longer in the endoleak group than in the non-endoleak group ($p = 0.031$ and $p = 0.010$, respectively). There were no statistically significant differences between

Table 2. Comparison of aortic morphological parameters between the two groups.

Variable	Non-endoleak group (n = 183)	Endoleak group (n = 38)	Statistic	*p* value
DATI (%)	18.3 ± 7.2	26.1 ± 8.5	$t = -5.884$	<0.001
Proximal landing zone diameter (mm)	34.5 ± 3.8	36.4 ± 4.2	$t = -2.754$	0.006
Proximal landing zone length (mm)	20.5 ± 6.0	16.5 ± 5.3	$t = 3.811$	<0.001
Distance from proximal primary entry tear to LSA (mm)	18.8 ± 9.2	13.8 ± 8.3	$t = 3.098$	0.002
Aortic arch angle (degrees)	127.2 ± 14.5	118.3 ± 15.6	$t = 3.398$	0.001
Proximal landing zone angulation (degrees)	24.3 ± 10.5	33.2 ± 12.6	$t = -4.587$	<0.001
Dissection involving abdominal aorta, n (%)	131 (71.6)	30 (78.9)	$\chi^2 = 0.862$	0.353
Dissection involving iliac artery, n (%)	95 (51.9)	22 (57.9)	$\chi^2 = 0.452$	0.501
Maximum false lumen diameter (mm)	25.2 ± 6.7	28.8 ± 7.3	$t = -2.876$	0.005
Minimum true lumen diameter (mm)	17.6 ± 5.5	14.0 ± 5.2	$t = 3.705$	<0.001
Primary entry tear location, n (%)			$\chi^2 = 2.448$	0.294
≤2 cm distal to LSA	72 (39.3)	20 (52.6)		
2–5 cm distal to LSA	68 (37.2)	12 (31.6)		
>5 cm distal to LSA	43 (23.5)	6 (15.8)		
Primary entry tear size (mm)	15.3 ± 6.2	18.8 ± 7.1	$t = -3.086$	0.002

Note: DATI, descending aortic tortuosity index; LSA, left subclavian artery. Continuous variables are presented as mean ± standard deviation, and categorical variables are presented as counts (percentages). χ^2 denotes the Pearson χ^2 test statistic; t denotes the independent-samples t test statistic; p values are two-sided.

the two groups in the incidence of perioperative complications or timing of the first postoperative CTA (all $p > 0.05$). In-hospital mortality was 0 in both groups (Table 3).

3.5 Extent of Dissection, Distal Residual Dissection, and Adjunctive Stabilization Techniques

Thoracoabdominal aortic dissection was present in 161 patients (72.9%), iliac artery involvement in 117 (52.9%), and visible distal re-entry tears in 146 (66.1%). Thirty-five patients (15.8%) received distal bare-stent/PETTICOAT-like support distal to the TEVAR segment, and 6 (2.7%) received STABILISE-like balloon-assisted intimal flap stabilization. No patient underwent Candy-Plug false-lumen occlusion during the initial procedure. Among patients with thoracoabdominal aortic dissection, the proportion with distal residual false lumen perfusion was higher in the endoleak group than in the non-endoleak group (80.0% vs 51.1%, $p = 0.004$) (Table 4).

3.6 Distal Landing Zone and Aortic Coverage Length

The overall aortic coverage length was 179.7 ± 36.9 mm. The coverage length was 186.7 ± 39.2 mm in the endoleak group and 178.2 ± 36.4 mm in the non-endoleak group, with no statistically significant difference ($p = 0.198$). In contrast, the distal landing zone length was shorter in the endoleak group than in the non-endoleak group (23.1 ± 8.8 mm vs 28.7 ± 9.5 mm, $p = 0.001$), and the proportion of patients with an effective distal landing zone ≥20 mm was also lower (65.8% vs 85.2%, $p = 0.005$) (Table 5).

3.7 Logistic Regression Analysis of Factors Associated With Postoperative Endoleak

Only clinically relevant preoperative aortic morphological parameters and intraoperative variables were included in the univariable logistic regression analysis; postoperative in-hospital outcomes and long-term follow-up events were not included in the prediction model. The results showed that DATI, proximal landing zone diameter, proximal landing zone length, distance from the proximal primary entry tear to the LSA, aortic arch angle, proximal landing zone angulation, maximum false lumen diameter, minimum true lumen diameter, primary entry tear size, stent-graft oversizing rate, and immediate intraoperative endoleak were all associated with postoperative endoleak (all $p < 0.05$) (Table 6).

Because there were 38 positive outcome events, the number of covariates included in the multiple model was limited to 3 to satisfy the EPV ≥10 principle. After multicollinearity assessment of candidate variables, the VIFs for DATI, proximal landing zone length, and immediate intraoperative endoleak were all <2.5. Based on clinical relevance and statistical results, DATI, proximal landing zone length, and immediate intraoperative endoleak were entered into the multiple logistic regression model using the Enter method. The results showed that DATI (OR = 1.09, 95% CI: 1.04–1.14, $p < 0.001$), proximal landing zone length (OR = 0.91, 95% CI: 0.85–0.98, $p = 0.008$), and immediate intraoperative endoleak (OR = 2.85, 95% CI: 1.08–7.52, $p = 0.034$) were independently associated with postoperative endoleak. The Hosmer–Lemeshow test indicated good model fit ($\chi^2 = 6.82$, $p = 0.338$) (Table 7).

Table 3. Comparison of procedural and perioperative data between the two groups.

Variable	Non-endoleak group (n = 183)	Endoleak group (n = 38)	Statistic	*p* value
Proximal landing zone location, n (%)			$\chi^2 = 1.282$	0.527
Zone 2	42 (23.0)	12 (31.6)		
Zone 3	118 (64.5)	22 (57.9)		
Zone 4	23 (12.6)	4 (10.5)		
LSA coverage, n (%)	52 (28.4)	14 (36.8)	$\chi^2 = 1.044$	0.307
LSA reconstruction/LSA coverage, n/N (%)	28/52 (53.8)	8/14 (57.1)	-	1.000†‡
Chimney/fenestration technique, n (%)	22 (12.0)	6 (15.8)	$\chi^2 = 0.397$	0.529
Stent-graft oversizing rate (%)	7.5 ± 3.8	9.2 ± 4.5	$t = -2.428$	0.016
Immediate intraoperative endoleak, n (%)	18 (9.8)	10 (26.3)	$\chi^2 = 7.723$	0.005
Concomitant intraoperative management rate (only patients with immediate intraoperative endoleak), n/N (%)	15/18 (83.3)	8/10 (80.0)	-	1.000†§
ICU stay (days)	2 (1, 4)	3 (2, 5)	$Z = -2.156$	0.031
Hospital stay (days)	12 (9, 16)	15 (11, 20)	$Z = -2.583$	0.010
Perioperative complications, n (%)	22 (12.0)	8 (21.1)	$\chi^2 = 2.182$	0.140
Stroke	3 (1.6)	1 (2.6)		
Spinal cord ischemia	5 (2.7)	2 (5.3)		
Acute kidney injury	8 (4.4)	3 (7.9)		
Access-related complications	6 (3.3)	2 (5.3)		
Timing of first postoperative CTA (days)	7 (5, 10)	7 (5, 9)	$Z = -0.312$	0.755
In-hospital mortality, n (%)	0 (0.0)	0 (0.0)	-	-

Note: LSA, left subclavian artery; ICU, intensive care unit; CTA, computed tomography angiography. Continuous variables are presented as mean ± standard deviation or median (interquartile range), according to distribution; categorical variables are presented as counts (percentages) or counts/denominator (percentages). χ^2 denotes the Pearson χ^2 test statistic; t denotes the independent-samples t test statistic; Z denotes the Mann–Whitney U test statistic; p values are two-sided. † Fisher's exact test. ‡ The LSA reconstruction rate was calculated using patients with LSA coverage as the denominator. § The concomitant intraoperative management rate was compared only among patients with immediate intraoperative endoleak. Because there were no in-hospital deaths in either group, no between-group test was performed.

3.8 Discriminatory Performance of DATI for Postoperative Endoleak and Cutoff-Based Stratified Analysis

ROC curve analysis showed that the AUC of DATI for predicting postoperative endoleak was 0.783 (95% CI: 0.710–0.856, $p < 0.001$). The optimal cutoff value determined by the Youden index was 22.5%, with a sensitivity of 71.1% and a specificity of 74.3% (Table 8, **Supplementary Fig. 3**). Using DATI = 22.5% as the cutoff value, the 221 patients were divided into a high-tortuosity group (DATI ≥22.5%, n = 74) and a low-tortuosity group (DATI <22.5%, n = 147). The incidence of postoperative endoleak was 36.5% (27/74) in the high-tortuosity group and 7.5% (11/147) in the low-tortuosity group, with a statistically significant difference ($\chi^2 = 29.081$, $p < 0.001$).

3.9 Exploratory Subgroup Analysis of DATI and Endoleak Type

Exploratory endoleak subtype analysis showed that DATI was most strongly associated with type I endoleak, especially type IA endoleak. For each 1% increase in DATI, the OR for any type I endoleak was 1.10 (95% CI: 1.05–1.16, $p < 0.001$), the OR for type IA endoleak was 1.11 (95% CI: 1.05–1.18, $p < 0.001$), and the OR for type IB endoleak was 1.08 (95% CI: 1.01–1.16, $p = 0.035$). The association between DATI and combined type II/III endoleak did not reach statistical significance (OR = 1.03, 95% CI: 0.94–1.12, $p = 0.540$) (Table 9, **Supplementary Fig. 4**).

3.10 Association Between DATI and Time to Postoperative Endoleak Onset

Kaplan–Meier analysis showed that patients with DATI ≥22.5% had significantly lower endoleak-free survival than those with DATI <22.5% (log-rank $p < 0.001$). The 12-month endoleak-free survival rate was 67.3% in the high-tortuosity group and 93.1% in the low-tortuosity group. Cox regression showed that DATI as a continuous variable was associated with time to endoleak onset (HR = 1.08 per 1% increase, 95% CI: 1.04–1.12, $p < 0.001$). After adjustment for proximal landing zone length and immediate intraoperative endoleak, DATI ≥22.5% remained associated with endoleak occurrence (adjusted HR = 4.38, 95%

Table 4. Extent of dissection, distal residual dissection, and adjunctive stabilization techniques.

Indicator	Non-endoleak group (n = 183)	Endoleak group (n = 38)	Overall cohort (n = 221)	Statistical method and statistic	*p* value
Dissection involving thoracic aorta only	52 (28.4)	8 (21.1)	60 (27.1)	$\chi^2 = 0.862$	0.353
Thoracoabdominal aortic dissection	131 (71.6)	30 (78.9)	161 (72.9)	$\chi^2 = 0.862$	0.353
Dissection involving iliac artery	95 (51.9)	22 (57.9)	117 (52.9)	$\chi^2 = 0.452$	0.501
Visible distal re-entry tear	116 (63.4)	30 (78.9)	146 (66.1)	$\chi^2 = 3.398$	0.065
Distal bare-stent/PETTICOAT-like support distal to the TEVAR segment	28 (15.3)	7 (18.4)	35 (15.8)	$\chi^2 = 0.230$	0.632
STABILISE-like balloon-assisted intimal flap stabilization	5 (2.7)	1 (2.6)	6 (2.7)	Fisher's exact test; OR = 0.962 (endoleak group vs non-endoleak group)	1.000
Candy-Plug false lumen occlusion	0 (0.0)	0 (0.0)	0 (0.0)	-	-
Distal residual false lumen perfusion during follow-up among patients with thoracoabdominal dissection	67/131 (51.1)	24/30 (80.0)	91/161 (56.5)	Fisher's exact test; OR = 3.821 (endoleak group vs non-endoleak group)	0.004

Note: Categorical variables are presented as counts (percentages). TEVAR, thoracic endovascular aortic repair; PETTICOAT, provisional extension to induce complete attachment; STABILISE, stent-assisted balloon-induced intimal disruption and relamination in aortic dissection; OR, odds ratio; χ^2, Pearson χ^2 test statistic. *p* values are two-sided. Fisher's exact test was used for comparisons with small expected frequencies; ORs were calculated for the endoleak group relative to the non-endoleak group. '-' indicates that no between-group test was performed.

Table 5. Distal landing zone and aortic coverage length.

Indicator	Non-endoleak group (n = 183)	Endoleak group (n = 38)	Overall cohort (n = 221)	Statistic	*p* value
Distal landing zone length (mm)	28.7 ± 9.5	23.1 ± 8.8	27.7 ± 9.6	$t = 3.347$	0.001
Distal landing zone diameter (mm)	27.6 ± 4.7	28.8 ± 5.1	27.8 ± 4.8	$t = -1.411$	0.160
Effective distal landing zone ≥20 mm	156 (85.2)	25 (65.8)	181 (81.9)	$\chi^2 = 8.036$	0.005
Aortic coverage length (mm)	178.2 ± 36.4	186.7 ± 39.2	179.7 ± 36.9	$t = -1.293$	0.198

Note: Continuous variables are presented as mean ± standard deviation, and categorical variables are presented as counts (percentages). *t* denotes the independent-samples *t* test statistic; χ^2 denotes the Pearson χ^2 test statistic; *p* values are two-sided.

Table 6. Univariable logistic regression analysis of postoperative endoleak (variables with $p < 0.10$ only).

Variable	OR	95% CI	*p* value
DATI (per 1% increase)	1.11	1.07–1.16	<0.001
Proximal landing zone diameter (per 1-mm increase)	1.12	1.03–1.22	0.007
Proximal landing zone length (per 1-mm increase)	0.89	0.84–0.95	<0.001
Distance from proximal primary entry tear to LSA (per 1-mm increase)	0.94	0.90–0.98	0.003
Aortic arch angle (per 1-degree increase)	0.96	0.94–0.99	0.002
Proximal landing zone angulation (per 1-degree increase)	1.07	1.04–1.11	<0.001
Maximum false lumen diameter (per 1-mm increase)	1.07	1.02–1.12	0.004
Minimum true lumen diameter (per 1-mm increase)	0.88	0.82–0.94	<0.001
Primary entry tear size (per 1-mm increase)	1.07	1.02–1.12	0.003
Stent-graft oversizing rate (per 1% increase)	1.10	1.02–1.19	0.017
Immediate intraoperative endoleak (yes vs no)	3.27	1.36–7.83	0.008

Note: DATI, descending aortic tortuosity index; LSA, left subclavian artery; OR, odds ratio; 95% CI, 95% confidence interval. ORs were calculated according to the units or categorical comparisons shown in parentheses for each variable; *p* values are two-sided.

Table 7. Multiple logistic regression analysis of postoperative endoleak.

Variable	b	SE	Wald χ^2	OR	95% CI	*p* value
DATI (per 1% increase)	0.086	0.024	12.84	1.09	1.04–1.14	<0.001
Proximal landing zone length (per 1-mm increase)	−0.094	0.036	6.82	0.91	0.85–0.98	0.008
Immediate intraoperative endoleak (yes vs no)	1.047	0.495	4.48	2.85	1.08–7.52	0.034
Constant	−2.316	0.872	7.06	-	-	0.008

Note: DATI, descending aortic tortuosity index; b, unstandardized regression coefficient; SE, standard error; OR, odds ratio; 95% CI, 95% confidence interval; Wald χ^2, Wald χ^2 test statistic. ORs were calculated according to the units or categorical comparisons shown in parentheses for each variable; *p* values are two-sided. Hosmer–Lemeshow test: $\chi^2 = 6.82$, $p = 0.338$.

Table 8. ROC curve analysis of DATI for predicting postoperative endoleak.

Indicator	Value
AUC (95% CI)	0.783 (0.710–0.856)
p value	<0.001
Optimal cutoff value	22.5%
Sensitivity	71.1%
Specificity	74.3%
Youden index	0.454

Note: DATI, descending aortic tortuosity index; ROC, receiver operating characteristic; AUC, area under the ROC curve; 95% CI, 95% confidence interval. The Youden index was used to determine the optimal cutoff value; the *p* value is the two-sided test result comparing the AUC with 0.5.

CI: 2.08–9.21, $p < 0.001$). Schoenfeld residual testing did not indicate an obvious violation of the proportional hazards assumption ($p = 0.624$) (Tables 10,11, **Supplementary Fig. 5**).

3.11 False Lumen Perfusion and False Lumen Thrombosis Status

Postoperative CTA showed complete false-lumen thrombosis in the stent-graft-covered thoracic aortic segment in 151 patients (68.3%), partial thrombosis in 56 (25.3%), and persistent patency/perfusion in 14 (6.3%). The proportion of complete thrombosis was lower in the endoleak group than in the non-endoleak group (42.1% vs 73.8%, $p < 0.001$). Compared with the non-endoleak group, the endoleak group had a higher proportion of any false lumen perfusion in the stent-graft-covered thoracic aortic segment (57.9% vs 26.2%, $p < 0.001$). Among the 161 patients with thoracoabdominal aortic dissection, complete thrombosis of the distal residual false lumen was observed in 70 (43.5%), partial thrombosis in 69 (42.9%), and persistent patency/perfusion in 22 (13.7%). Distal residual false lumen perfusion was defined as partial thrombosis or persistent patency/perfusion; its proportion was 24/30 (80.0%) in the endoleak group and 67/131 (51.1%) in the non-endoleak group ($p = 0.004$) (Table 12, **Supplementary Fig. 6**).

4. Discussion

The results of this study suggest that preoperative DATI may be independently associated with persistent or new-onset endoleak after TEVAR in this study cohort. Given that this was a single-center retrospective analysis, DATI should be interpreted as a hypothesis-generating supplemental morphological indicator rather than a validated causal determinant. The DATI cutoff value of 22.5% requires multicenter external validation before clinical application.

Endoleak is a key complication affecting aortic remodeling after TEVAR, and type I endoleak has particularly important clinical significance because it directly reflects proximal or distal sealing failure [9]. In this cohort, the incidence of persistent or new-onset postoperative endoleak was 17.2%, which was generally consistent with endoleak rates reported in contemporary TEVAR studies [10,11]. Type IA endoleak accounted for the largest proportion (57.9%), suggesting that proximal sealing failure remains the main problem. This finding is closely related to the structural fragility of the aortic wall in the acute phase, dissection involvement of the proximal landing zone, and the complex geometry of the aortic arch and proximal descending aorta [12].

This study further analyzed endoleak types as exploratory outcomes. DATI was most strongly associated with type I endoleak, especially type IA endoleak, whereas no significant association was observed for combined type II/III endoleak. This finding is biologically plausible: overall descending aortic tortuosity may affect passage of the stent-graft delivery system, coaxial deployment, and proximal stent-graft apposition, thereby increasing the risk of poor proximal sealing. In contrast, type II endoleak is mainly caused by retrograde perfusion through branch arteries, and type III endoleak is more often related to device connection or material problems; their mechanisms may not be directly determined by overall descending aortic tortuosity. Because the number of type II and III events was small, separate multiple models were not constructed for them, and the related results should be interpreted only as exploratory findings.

As an objective quantitative indicator of vascular curvature, the tortuosity index has previously been shown

Table 9. Exploratory predictive analysis of DATI for different endoleak types.

Outcome	Number of events	DATI in event group (%)	DATI in non-event group (%)	Model	OR (95% CI)	*p* value
Any endoleak	38	26.1 ± 8.5	18.3 ± 7.2	Multiple logistic regression	OR = 1.09 (95% CI: 1.04–1.14)	<0.001
Type I endoleak (IA+IB)	30	27.0 ± 8.2	18.9 ± 7.4	Firth univariable logistic regression	OR = 1.10 (95% CI: 1.05–1.16)	<0.001
Type IA endoleak	22	27.8 ± 8.1	19.2 ± 7.7	Firth univariable logistic regression	OR = 1.11 (95% CI: 1.05–1.18)	<0.001
Type IB endoleak	8	26.8 ± 8.4	19.7 ± 7.8	Firth univariable logistic regression	OR = 1.08 (95% CI: 1.01–1.16)	0.035
Type II/III endoleak	8	22.7 ± 8.2	20.0 ± 7.9	Firth univariable logistic regression	OR = 1.03 (95% CI: 0.94–1.12)	0.540

Note: DATI, descending aortic tortuosity index; OR, odds ratio; 95% CI, 95% confidence interval. DATI values in event and non-event groups are presented as mean ± standard deviation. The result for any endoleak was derived from multiple logistic regression, whereas the results for other endoleak subtypes were derived from Firth penalized likelihood univariable logistic regression; *p* values are two-sided.

Table 10. Cox regression analysis of DATI and time to postoperative endoleak onset.

Model	Variable	HR	95% CI	*p* value	Adjustment variables/test
Model 1: continuous variable	DATI per 1% increase	1.08	1.04–1.12	<0.001	Unadjusted
Model 2: dichotomous variable	DATI ≥22.5% vs <22.5%	5.42	2.67–10.99	<0.001	Unadjusted
Model 3: adjusted model	DATI ≥22.5% vs <22.5%	4.38	2.08–9.21	<0.001	Proximal landing zone length; immediate intraoperative endoleak
Proportional hazards assumption	Schoenfeld residual test	-	-	0.624	Schoenfeld residual test
Kaplan–Meier comparison	DATI ≥22.5% vs <22.5%	-	-	<0.001	log-rank test

Note: DATI, descending aortic tortuosity index; HR, hazard ratio; 95% CI, 95% confidence interval. HRs were calculated according to the comparisons shown in the variable column. The log-rank test was used to compare Kaplan–Meier curves between groups; the Schoenfeld residual test was used to evaluate the proportional hazards assumption; *p* values are two-sided.

Table 11. Endoleak-free survival rates and numbers at risk stratified by the DATI cutoff value.

Time point (months)	Endoleak-free survival for DATI ≥22.5%	Number at risk for DATI ≥22.5%	Endoleak-free survival for DATI <22.5%	Number at risk for DATI <22.5%
0	100.0	74	100.0	147
6	75.0	52	93.8	111
12	67.3	39	93.1	78
18	63.5	23	92.3	48
24	60.8	12	91.5	26

Note: Endoleak-free survival values are expressed as percentages. DATI, descending aortic tortuosity index. Endoleak-free survival rates were estimated using the Kaplan–Meier method; numbers at risk refer to the number of patients still under follow-up and without the primary outcome event before the corresponding time point.

to be associated with postoperative endoleak and device-related adverse events in endovascular abdominal aortic aneurysm repair [6,7]. In the present study, DATI was significantly higher in the endoleak group than in the non-endoleak group. In multiple analyses, each 1% increase in DATI corresponded to an OR of 1.09 (95% CI: 1.04–1.14), suggesting that the risk of postoperative endoleak may increase continuously with greater descending aortic tortuosity. Mechanistically, increased descending aortic tortuosity may cause uneven axial tension during passage of the stent-graft delivery sheath, impair coaxial deployment, lead to poor apposition between the proximal or distal stent-graft and the aortic wall, and cause uneven stress distribution in the sealing zone [13,14]. In addition, in markedly tortuous anatomy, the radial support force of the stent-graft may not be transmitted uniformly to the landing zone, thereby increasing the likelihood of micromotion, friction, and persistent sealing-zone leakage [15].

False lumen perfusion and distal residual dissection are important imaging issues in the assessment of aortic

Table 12. Proportions of false lumen thrombosis after TEVAR.

Assessment site and status	Non-endoleak group	Endoleak group	Overall cohort	Statistic	*p* value
Stent-graft-covered thoracic aorta: complete thrombosis	135/183 (73.8)	16/38 (42.1)	151/221 (68.3)	χ^2 = 14.579 (complete vs incomplete)	<0.001
Stent-graft-covered thoracic aorta: partial thrombosis	39/183 (21.3)	17/38 (44.7)	56/221 (25.3)	-	-
Stent-graft-covered thoracic aorta: persistent patency/perfusion	9/183 (4.9)	5/38 (13.2)	14/221 (6.3)	-	-
Stent-graft-covered thoracic aorta: any false lumen perfusion	48/183 (26.2)	22/38 (57.9)	70/221 (31.7)	χ^2 = 14.579	<0.001
Residual thoracoabdominal dissected segment: complete thrombosis	64/131 (48.9)	6/30 (20.0)	70/161 (43.5)	Fisher's exact test; OR = 0.262 (endoleak group vs non-endoleak group)	0.004
Residual thoracoabdominal dissected segment: partial thrombosis	55/131 (42.0)	14/30 (46.7)	69/161 (42.9)	-	-
Residual thoracoabdominal dissected segment: persistent patency/perfusion	12/131 (9.2)	10/30 (33.3)	22/161 (13.7)	-	-
Residual thoracoabdominal dissected segment: any false lumen perfusion	67/131 (51.1)	24/30 (80.0)	91/161 (56.5)	Fisher's exact test; OR = 3.821 (endoleak group vs non-endoleak group)	0.004

Note: Categorical variables are presented as counts (percentages). TEVAR, thoracic endovascular aortic repair; OR, odds ratio; χ^2, Pearson χ^2 test statistic. In the statistical method column, 'complete vs incomplete' indicates a dichotomous comparison of complete thrombosis versus incomplete thrombosis. Fisher's exact test was used for comparisons with small expected frequencies; ORs were calculated for the endoleak group relative to the non-endoleak group. *p* values are two-sided. '-' indicates that no separate between-group test was performed or that the comparison was not applicable.

remodeling after endovascular treatment of acute TBAD. This cohort was not limited to dissections confined to the thoracic aorta; 72.9% of patients had thoracoabdominal aortic dissection, and 66.1% had visible distal re-entry tears. For distal residual dissection, our center mainly adopts intensive medical therapy and sequential CTA follow-up. Distal bare-stent/PETTICOAT-like support is used selectively only when persistent dynamic malperfusion, severe true lumen compression, or insufficient distal true lumen expansion is present; STABILISE-like techniques are used only in highly selected cases; and Candy-Plug false lumen occlusion was not used during the initial procedure. This strategy helps avoid excessive intervention in the acute phase while preserving the possibility of subsequent reassessment and reintervention in patients with persistent residual false-lumen perfusion.

The results for postoperative false lumen thrombosis showed that the complete thrombosis rate in the stent-graft-covered thoracic aortic segment was 68.3%, whereas the covered-segment complete thrombosis rate was markedly lower in the endoleak group than in the non-endoleak group. The complete thrombosis rate in the residual thoracoabdominal dissected segment was 43.5%, lower than that in the covered thoracic aortic segment, which is consistent with the pathophysiological feature that TEVAR primarily seals the proximal primary entry tear while distal re-entry tears may continue to maintain residual false lumen perfusion. The higher proportion of distal residual false lumen perfusion in the endoleak group suggests that postoperative endoleak and persistent false lumen perfusion/incomplete thrombosis may promote each other; however, the present study design cannot establish the direction of causality.

The distal landing zone is a key anatomical factor influencing type IB endoleak and distal sealing stability. In this study, the distal landing zone was defined as the true lumen segment immediately adjacent to the distal edge of the thoracic aortic stent-graft and was measured as the centerline distance from the distal edge of the stent-graft to the nearest major distal re-entry tear or to the level of the celiac trunk. The results showed that the distal landing zone length was shorter and the proportion of effective distal landing zone ≥20 mm was lower in the endoleak group, whereas aortic coverage length did not differ significantly between groups. These findings indicate that in this cohort, simply increasing coverage length may not necessarily reduce endoleak risk; the key factors remain effective apposition in the proximal and distal sealing zones, true lumen support, and re-entry tear location.

Multiple regression analysis also showed that proximal landing zone length and immediate intraoperative endoleak were associated with postoperative endoleak. Insufficient landing zone length reduces the sealing surface area and is a classic risk factor for endoleak, consistent with previous studies [16,17]. The mechanism by which immediate

intraoperative endoleak predicts follow-up endoleak may be that an endoleak detected on intraoperative angiography indicates a structural defect in the sealing zone. Even if it improves immediately after intraoperative management, the locally fragile anatomical region may still recur under subsequent hemodynamic stress [18]. It is noteworthy that the stent-graft oversizing rate was higher in the endoleak group than in the non-endoleak group; however, because of the number of events and the limit on the number of variables in the final model, the stent-graft oversizing rate was not included in the final multiple model, and its independent effect requires further investigation. The effect of oversizing on endoleak may be partly mediated by tortuosity and landing zone anatomy, but this inference requires validation in larger samples [19].

Time-to-event analysis further showed that DATI was associated with time to endoleak onset. Kaplan–Meier curves showed that patients with DATI ≥22.5% had significantly lower endoleak-free survival than those with DATI <22.5%. In Cox regression, DATI was associated with endoleak occurrence both as a continuous variable and after stratification at 22.5%. Because endoleaks in the high-DATI group were not only more frequent but also occurred earlier, postoperative follow-up strategies may need to be intensified for patients with severe tortuosity, especially when no obvious endoleak is found on the first postoperative CTA but sealing-zone apposition or false lumen thrombosis remains insufficient.

From a clinical application perspective, DATI can be obtained from routine preoperative CTA centerline reconstruction and is relatively easy to measure. Preoperatively, it may be used together with morphological information such as proximal and distal landing zone lengths for risk stratification and procedural planning. Immediate intraoperative endoleak and postoperative false lumen perfusion/thrombosis status may further serve as adjuncts for intensified follow-up and reintervention assessment. For patients with DATI ≥22.5%, the proximal and distal sealing zone conditions should be thoroughly evaluated preoperatively; when necessary, the proximal landing strategy should be optimized, coaxial deployment control should be strengthened, and tolerance for immediate intraoperative endoleak should be reduced. For patients with thoracoabdominal aortic dissection, distal re-entry tears, or residual false lumen perfusion, postoperative attention should be paid to false lumen thrombosis in both the covered segment and the distal residual segment to identify adverse aortic remodeling or the need for reintervention in a timely manner [20,21].

5. Limitations

This study has several limitations. First, it was a single-center retrospective study and therefore may be subject to selection bias. Second, because of the limited number of events, the number of variables included in the multiple logistic regression model was limited; event numbers were small in endoleak subtype analyses, especially for type IB, type II, and type III endoleaks. Therefore, subgroup results should be considered hypothesis-generating rather than definitive evidence. Third, the median follow-up duration was 12 months, and the predictive value of DATI for late endoleak, distal residual dissection expansion, and reintervention requires further evaluation with longer follow-up. Fourth, the DATI cutoff value of 22.5% proposed in this study was derived from ROC analysis in this cohort and has not yet been validated in an external cohort; therefore, it should not be used directly as a standalone clinical decision rule.

6. Conclusions

In this single-center retrospective study, preoperative DATI may be independently associated with persistent or new-onset endoleak after TEVAR in patients with acute complicated Stanford type B aortic dissection and may have moderate discriminatory ability. DATI ≥22.5% may indicate a higher risk of endoleak during follow-up, especially type I and type IA endoleaks. Preoperatively, DATI may be combined with proximal landing zone length, distal landing zone conditions, and other morphological information for risk stratification and procedural planning. Immediate intraoperative endoleak and postoperative false lumen perfusion/thrombosis status may further assist in intensified postoperative follow-up. Given the limitations of the study design and single-center sample, these findings still require confirmation in multicenter, prospective, and externally validated studies.

Availability of Data and Materials

The datasets generated or analyzed during the current study are not publicly available because they contain patient-related information and are protected under the institutional ethics protocol, but are available from the corresponding author on reasonable request.

Author Contributions

YHT and SYS conceived and designed the study. YHT, ZFH, and JYW collected the clinical, imaging, and perioperative data. CJL contributed to data verification and methodological support. YHT and SYS performed the statistical analysis and interpreted the data. YHT drafted the manuscript. ZFH, JYW, CJL, and SYS critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript and agreed to be accountable for all aspects of the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Nanjing BenQ Medical Center, Affiliated Hospital of Nanjing Medical University (Approval No.: 2026-KL030). The study was conducted in accordance with the Declaration of Helsinki. As this was a retrospective observational study, the requirement for informed consent was waived by the ethics committee.

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Conflicts of Interest

The authors declare no conflicts of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.31083/HSF52831.

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