

Proximal Aortic Landing Zone Dilation Following Thoracic Endovascular Aortic Repair for Type B Aortic Dissection: Incidence and Clinical Implications

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Background: This study aimed to assess the incidence, predictors, and clinical relevance of proximal aortic landing zone dilation (PALD) following thoracic endovascular aortic repair (TEVAR) for acute and chronic type B aortic dissection (TBAD).

Methods: A retrospective analysis of 47 patients who underwent TEVAR for TBAD at a single center was conducted. PALD was defined as a ≥ 5 mm increase in aortic diameter at 2 of 3 measurement sites (at 0, 1, and 2 cm distal to the stent graft proximal edge) at postoperative computed tomography angiography. The primary endpoint was the development of PALD. Secondary endpoints included entry flow type IA, device migration and reintervention rates. Kaplan-Meier analyses was used to evaluate PALD-free survival.

Results: PALD occurred in 19% of patients ($n = 9$) during a median follow-up of 62 months. A stent graft diameter > 36 mm significantly predicted PALD ($P = 0.022$), with an area under the curve of 0.75 (sensitivity: 89%, specificity: 58%). No significant associations were found between PALD and reinterventions or type Ia entry flow. Kaplan-Meier analysis revealed a median PALD-free survival of 156 months (95% confidence interval: 92–210). Patients with PALD demonstrated a greater increase in aortic diameter at maximum follow-up compared to non-PALD patients ($P < 0.001$). Other demographic, anatomic, and procedural factors were not associated with PALD, and especially oversizing did not correlate with PALD development.

Conclusion: PALD occurred in a significant proportion of patients following TEVAR for TBAD, with stent graft diameter serving as key predictor. PALD did not correlate with adverse clinical outcomes in this cohort.

INTRODUCTION

Thoracic endovascular aortic repair (TEVAR) has significantly advanced the management of thoracic aortic pathologies by providing a less invasive alternative to open surgery with favorable short- and long-term outcomes.¹ However, TEVAR is not

without limitations, and complications such as stent graft migration and endoleaks caused by aortic neck dilation (AND) can occur and may necessitate secondary interventions, impacting the durability of aortic repair in some cases.^{2,3}

Aortic dilation after endovascular repair is a well-recognized phenomenon, with extensive research

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highlighting its incidence and implications in abdominal endovascular aneurysm repair.⁴ Similarly, TEVAR has been shown to affect the aortic morphology at the proximal landing zone when treating degenerative thoracic aortic aneurysms, albeit less consistently studied. Mechanical stresses exerted by the stent graft as well as progression of the underlying aneurysmal disease may result in morphological changes at the proximal aortic landing zone (PAL), and these changes may be further influenced by individual factors such as patient anatomy, device oversizing and comorbidities.^{2,5–7}

Focusing on type B aortic dissection (TBAD), PAL dilation (PALD) after TEVAR may have unique implications, and findings from studies on other pathologies should be applied to this disease entity with caution, as the aorta in TBAD patients is characterized by significant remodeling potential, particularly in the acute phase of dissection.^{8,9} Studies specifically addressing PALD in TBAD cases are scarce. Berkarda et al. investigated PAL remodeling in 101 patients, reporting a median increase of 3 mm over a mean follow-up (FU) duration of 2.3 years, but did not investigate risk factors and clinical relevance of this dilation regarding type IA entry flow or device migration.¹⁰ Yau et al. suggested a higher risk for PALD compared to patients managed for degenerative thoracic aortic aneurysm,⁷ but a small sample size and a short FU duration do not allow for any well-founded conclusions. Thus, critical questions remain unanswered.

Given these gaps, this study aims to assess the incidence, predictors and clinical relevance of PALD following TEVAR in TBAD patients. Using a single-center registry, we evaluate demographic, anatomical, and procedural factors associated with PALD. Furthermore, we explore the clinical implications of PALD, including its relationship with entry flow IA, device migration, secondary interventions and long-term outcomes, to provide a comprehensive understanding of its impact on the durability of aortic repair.

METHODS

Study Design

This retrospective, single-center cohort study evaluated patients who underwent TEVAR for the management of TBAD between 2006 and 2020. Reporting standards by the Society of Thoracic Surgeons and the Society for Vascular Surgery for TBADs and the Strengthening the Reporting of Observational Studies in Epidemiology guidelines were followed.^{11,12}

This study received approval from the institutional review board (IRB 19-1017_1) and complied with the Declaration of Helsinki. Patient confidentiality was maintained throughout the study, and informed consent was waived due to the retrospective nature of the study.

Data Collection and Measurements in Computed Tomography Angiography (CTA)

Data were extracted from an institutional database and included demographic characteristics (age, gender, comorbidities, American Society of Anesthesiologists classification, smoking status), procedural details (stent graft diameter, number of implanted stent grafts, additional procedures, oversizing, and type of stent graft), and clinical outcomes (development of PALD, type IA entry flow, device migration, reintervention rates).

Measurements were calculated on available CTA scans using a dedicated workstation (IMPAX EE R20 2019, AGFA HealthCare, Mortsels, Belgium). Multiplanar reconstruction was used to determine the outer-to-outer wall aortic diameter measured on cross-sectional images orthogonal to the center lumen of flow at different specific sites, as depicted in Figure 1. Type of aortic arch, length of aortic coverage, and proximal landing zone was also collected from CTA scans.¹³ After the first CTA, which had to be carried out within 30 days after TEVAR, measurements were performed on all available annual FU CTA scans for the first 48 months and on the CTA scan at maximum FU.

Measurements included the following:

- Maximum aortic diameter
- Aortic diameter 20-mm proximal to the stent graft proximal edge (+20) or A
- Aortic diameter 10-mm proximal to the stent graft proximal edge (+10) or B
- Aortic diameter at the stent graft proximal edge (0) or C
- Aortic diameter 10-mm distal to the stent graft proximal edge (–10) or D
- Aortic diameter 20-mm distal to the stent graft proximal edge (–20) or E
- Calcification or thrombus in the aortic neck

PALD was defined as a ≥ 5 -mm increase of aortic diameter in at least 2 of the measurement sites C, D, and/or E simultaneously.

Stent graft oversizing was assessed as relative difference between the stent grafts diameter and the

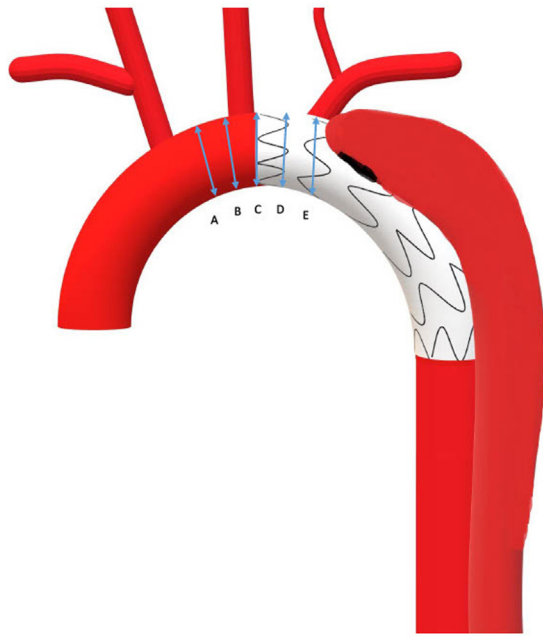


Fig. 1. Measurements of outer-to-outer wall aortic diameter performed at different sites.

mean diameter of measurement sites C, D, and E at baseline CTA.

Type IA entry flow was defined as a perigraft leak at the proximal edge of the stent graft that allows continued antegrade flow into the false lumen through the primary entry tear.¹¹

Device migration was defined as a stent graft shift of >10 mm relative to the origin of the left subclavian artery (LSA) if the device was placed in aortic landing zone III or relative to the origin of the left common carotid artery (LCCA) if the stent grafts was placed in aortic landing zone II as defined according to the TBAD reporting standards by Society of Thoracic Surgeons and the Society for Vascular Surgery.¹¹

Inclusion Criteria

Patients were included if they underwent technically successful TEVAR in native aortic landing zones II and III without hematoma proximally and IV and V distally for the treatment of acute or chronic complicated or uncomplicated TBAD.¹¹ The inclusion criteria required patients to be at least 18 years old and have a CTA scan, conducted within 30 days after TEVAR, accessible on the institutional picture archiving and communication system with an image slice thickness ≤ 2 mm and arterial-phase contrast timing. They were also required to have at least 1 FU CTA scan at 1 year postoperatively. No electrocardiogram gated or specific acquisition protocol was required.

Exclusion Criteria

Patients were excluded if TEVAR was performed for indications other than TBAD, if they had prior thoracic aortic surgery, if supra-aortic debranching beyond the LSA was performed, if they had a known genetic aortic syndrome or if imaging FU was insufficient.

Endpoints

The primary endpoint was PALD, defined as growth ≥ 5 mm at 2 of the 3 measurement sites at the PAL simultaneously. The study power was calculated using a 1-sample proportion with a normal approximation and continuity correction. The proportion was set at 0.25, with a nondirectional (2-sided) analysis and a significance level of 0.05, yielding a power of 93.7%.

Secondary endpoints included the annual increase in maximum aortic diameter, the development of entry flow, and reinterventions.

Statistical Analysis

Data were collected from patient records and CTA images. Statistical analyses were performed using SPSS 29.0 (IBM Corp., Armonk, NY). Data were expressed as median and min/max for nonparametric data and as mean with standard deviation for parametric data. The Mann-Whitney test for independent and Wilcoxon signed-rank test for dependent samples were used to compare continuous variables, and the chi-square test was used to compare the categorical variables. A *P* value of < 0.05 was considered statistically significant. Kaplan-Meier curves were employed to estimate the freedom of ≥ 5 mm aortic growth in the PAL.

Cox-regression analysis with forward stepwise method was used to identify the possible factors contributing to PALD.

RESULTS

During the study period, 168 patients underwent TEVAR for TBAD, with 47 meeting the inclusion criteria. The main exclusion criterion was the lack of adequate FU imaging. A flow chart in [Figure 2](#) illustrates the inclusion and exclusion process. Of the 47 individuals that were included in this study, 15 (32%) were female, 26 (55%) patients were older than 65 years, 33 (70%) were treated in the acute phase and 19 (40%) patients had complicated TBAD. Detailed baseline and procedural characteristics are provided in [Table I](#) and for patients treated in the acute phase separately in [Table II](#).

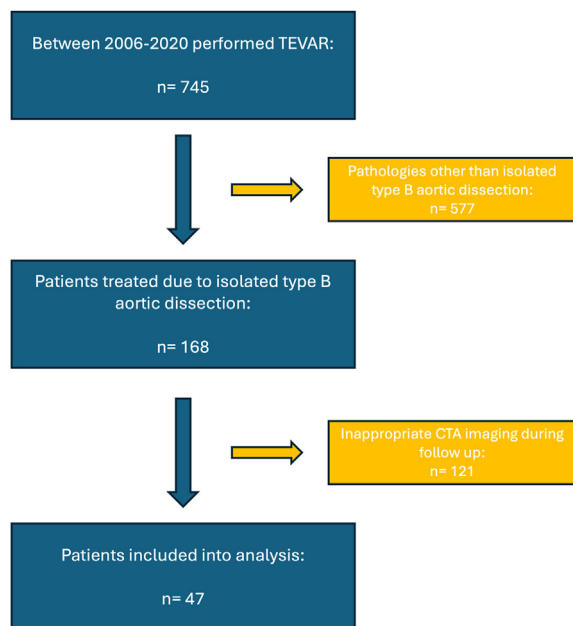


Fig. 2. Flow chart illustrating the inclusion and exclusion process.

PALD

Among the cohort, 9 patients (19%) developed PALD showing a ≥ 5 mm increase at 2 measurement sites (C, D, or E) simultaneously. Five patients (56%) developed PALD within the first 48 months post-TEVAR and 3 patients (33%) within the first 12 months. Compared to the other patients who developed PALD, these 3 patients were all male ($P = 0.018$) and had a larger median stent graft diameter of 40 mm (34, 40, $P = 0.029$). The median FU for the cohort was 62 months (range 11–160), with 70 months (range 11–156) in the PALD group and 62 months (range 15–160) in the no-PALD group. Table I provides a detailed overview of patient characteristics, which did not differ between PALD and no-PALD groups. No significant differences between groups were identified when excluding chronic cases (Table II).

Reinterventions, Device Migration and Aortic Growth

In this cohort, no type IA entry flow or device migration was observed in both PALD and no-PALD groups and no reinterventions at the PAL were performed.

A significant increase in median aortic diameter at maximum FU was observed at sites A (1 mm, $P < 0.001$), B (1 mm, $P < 0.001$), and C (2 mm, $P < 0.001$), but no increase in maximum aortic diameter during the FU period was noted

($P = 0.576$). Boxplots show detailed aortic diameter measurements at sites A–E at all available time-points for the PALD group (Fig. 3) and the no-PALD group (Fig. 4). The PAL grew larger than the nominal stent graft diameter in 13 patients with a median diameter increase of 4 (1, 16) mm.

Baseline Factors

Baseline factors were comparable between PALD and no-PALD groups. Age, gender, comorbidities, acuity of dissection, complication status, smoking status, and American Society of Anesthesiologists classification did not differ between groups (Table I).

Anatomic Parameters

The proximal landing zone did not significantly affect the development of PALD, as similar changes in aortic diameter were observed across all zones. There was no thrombus or calcification at the measurement sites A–E in any of the patients. No significant differences were found between the PALD and no-PALD groups concerning the type of aortic arch (Table I).

Technical Details

A larger stent graft diameter was associated with the development of PALD. The median stent graft diameter in the PALD group was 37 mm (range 34–40), compared to 34 mm (range 28–45) in the no-PALD group ($P = 0.017$). A cut-off value of 36 mm for stent graft diameter predicted PALD, with a sensitivity of 89% and a specificity of 58% (area under the curve 0.75, standard error 0.076, $P = 0.022$).

In 45 cases, a cTAG® or TAG® graft (W. L. Gore & Associates, Flagstaff, AZ, USA) was used, in 2 cases a Zenith Alpha® or TX2® graft (Cook Medical LLC, Bloomington, IN, USA) was implanted. Graft Type, number of placed stent grafts, length of aortic coverage or stent graft oversizing was not associated with development of PALD (Table I). Stent grafts were placed in landing zone 2 in 7 (78%) patients in PALD group and in 30 (79%) patients in the no-PALD group. LCCA to LSA bypass was performed in 5 of those 7 patients in PALD group and in 21 of 30 patients in the no-PALD group and neither landing zone nor placement of LCCA-LSA bypass was associated with the development of PALD. No other additional procedures to TEVAR procedure than LCCA-LSA were performed in this cohort.

PALD-free Survival and Predictive Factors

Kaplan-Meier analysis revealed a median PALD-free survival of 156 months (95% confidence

Table I. Baseline and procedural characteristics of 47 patients who underwent TEVAR for the treatment of TBAD

Patient's characteristics	PALD, <i>n</i> = 9 (19%)	No-PALD, <i>n</i> = 38 (81%)	<i>P</i> value
Female gender	5 (56%)	10 (26%)	0.091
Age >65	7 (78%)	16 (42%)	0.054
Complicated dissection	3 (33%)	16 (42%)	0.630
Acute dissection	5 (56%)	28 (74%)	0.285
Diabetes	1 (11%)	1 (3%)	0.257
Hypertension	8 (89%)	35 (92%)	0.756
Prior coronary artery disease	0	3 (8%)	0.384
Chronic obstructive pulmonary disease	2 (22%)	4 (10.5%)	0.344
Smoking	3 (33%)	19 (50%)	0.406
ASA classification			0.624
II	1 (11%)	6 (16%)	
III	6 (67%)	23 (60.5%)	
IV	1 (11%)	8 (21%)	
V	1 (11%)	1 (3%)	
Proximal landing zone			0.939
II	7 (78%)	30 (79%)	
III	2 (22%)	8 (21%)	
Type of aortic arch			0.954
I	3 (33%)	13 (34%)	
II	4 (44%)	15 (39.5%)	
III	2 (22%)	10 (26%)	
Type IA entry flow	0	0	
Device migration	0	0	
Need for reintervention at proximal aortic landing zone	0	0	
Oversizing of the stent graft (%)	10.7 ± 0.6	11.8 ± 1.1	0.705
Diameter of the stent graft	37 (34, 40)	34 (28, 45)	0.017
Number of placed stent grafts	1 (1, 4)	1 (1, 4)	0.469
Length of aortic coverage (cm)	20.6 ± 1.6	18.9 ± 6.6	0.317
Additional surgical procedure			
LCCA-LSA bypass	5 (56%)	21 (55%)	0.987
Type of stent graft			
Gore ^a (TAG, cTAG)	8	37	
Cook ^b (TX2, Alpha)	1	1	0.124

Data are presented as *n* (%), mean ± standard deviation and median (min, max).

ASA, American Society of Anesthesiologists.

^aW. L. Gore & Associates (Flagstaff-Arizona, USA).

^bCook medical LLC (Bloomington, USA).

interval: 92–210), as shown in Figure 5. Cox-regression analysis did not identify any of the investigated factors as predictors of PALD during FU.

DISCUSSION

In contrast to previous studies examining AND after TEVAR in degenerative aneurysms, this study found no significant association between PALD and reintervention rates in TBAD patients.² While 9 patients (19%) developed PALD, there were no reinterventions performed at the PAL in both cohorts, suggesting that PALD in TBAD may have a less severe

clinical impact than previously assumed. These findings differ from earlier studies that linked PALD to poorer long-term outcomes, highlighting the need for further research to delineate whether PALD in TBAD patients behaves differently from that in aneurysmal disease.

Demographic and procedural analysis did not reveal any correlations between PALD and the investigated factors apart from stent graft diameters of >36 mm.

The significant association between larger stent graft diameters and PALD reinforces the need for careful device selection and sizing, particularly in TBAD patients. In this context, an association

Table II. Baseline and procedural characteristics of 33 patients who underwent TEVAR for the treatment of acute TBAD

Patient's characteristics	PALD, <i>n</i> = 5	No-PALD, <i>n</i> = 28	<i>P</i> value
Female gender	2 (40%)	7 (25%)	0.488
Age >65	3 (60%)	12 (43%)	0.478
Complicated dissection	2 (40%)	15 (54%)	0.576
Diabetes	1 (20%)	1 (4%)	0.156
Hypertension	5 (100%)	25 (89%)	0.443
Prior coronary artery disease	0	2 (7%)	0.538
Chronic obstructive pulmonary disease	1 (20%)	3 (11%)	0.558
Smoking	1 (20%)	15 (54%)	0.344
ASA classification			0.357
II	1 (20%)	4 (14%)	
III	3 (60%)	16 (57%)	
IV	0	7 (25%)	
V	1 (20%)	1 (4%)	
Proximal landing zone			0.743
II	4 (80%)	24 (86%)	
III	1 (20%)	4 (14%)	
Type of aortic arch			0.380
I	3 (60%)	11 (39%)	
II	2 (40%)	9 (32%)	
III	0	8 (29%)	
Type IA entry flow	0	0	
Device migration	0	0	
Need for reintervention at proximal aortic landing zone	0	0	
Oversizing of the stent graft (%)	11.1 ± 0.8	11.7 ± 1.3	0.88
Diameter of the stent graft	37 (34, 40)	34 (28, 45)	0.200
Number of placed stent grafts	1 (1, 1)	1 (1, 4)	0.216
Length of aortic coverage (cm)	18.0 ± 1.2	18.6 ± 0.8	0.956
Additional surgical procedure			0.478
LCCA-LSA bypass	2 (40%)	16 (57%)	
Type of stent graft			
Gore ^a (TAG, cTAG)	5	33	
Cook ^b (TX2, Alpha)	0	0	

Data are presented as *n* (%), mean ± standard deviation and median (min, max).

ASA, American Society of Anesthesiologists.

^aW. L. Gore & Associates (Flagstaff-Arizona, USA).

^bCook medical LLC (Bloomington, USA).

between development of retrograde type A aortic dissection following TEVAR for uncomplicated type B aortic dissection and oversizing of >5% has been described.¹⁴

Exploring the potential biomechanical underpinnings of PALD in TBAD patients post-TEVAR, several factors warrant consideration. Biomechanical stresses exerted on the aortic wall by the stent graft, coupled with underlying aortic pathology, likely contribute to the development of PALD. Several studies have emphasized the consequences of heightened stiffness and increased radial force exerted on the aortic wall, which can subsequently precipitate stent graft—

related complications. These complications may include retrograde or antegrade dissection, as well as aortic dilatation, owing to elevated wall stress.^{15–18}

Yau et al.⁷ discovered a significant correlation between oversizing and neck growth in their cohort of 30 patients, comprising 15 with TBAD and 15 with aneurysm in the thoracic aorta. Their findings align with other studies investigating aortic biomechanical mechanisms, which used a combination of ex vivo and in silico analyses.⁶ These studies demonstrated that oversizing contributes significantly to shear wall stress, providing a potential explanation for observed aortic dilation corresponding with

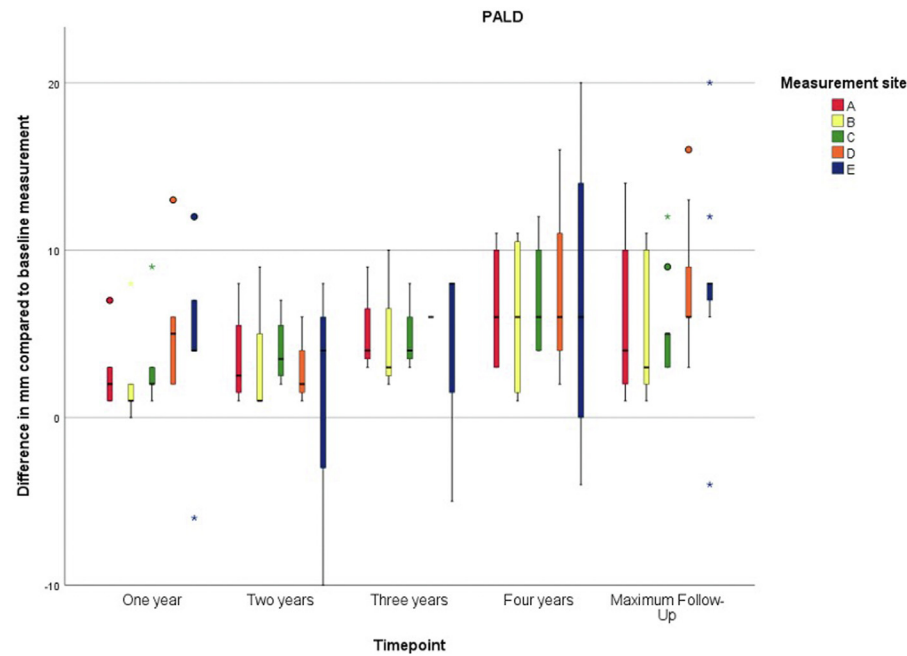


Fig. 3. Boxplots showing difference in mm at 1-, 2-, 3- and 4-year FU and at maximum FU at measurement sites A, B, C, D, and E compared to baseline measurements in patients that developed PALD.

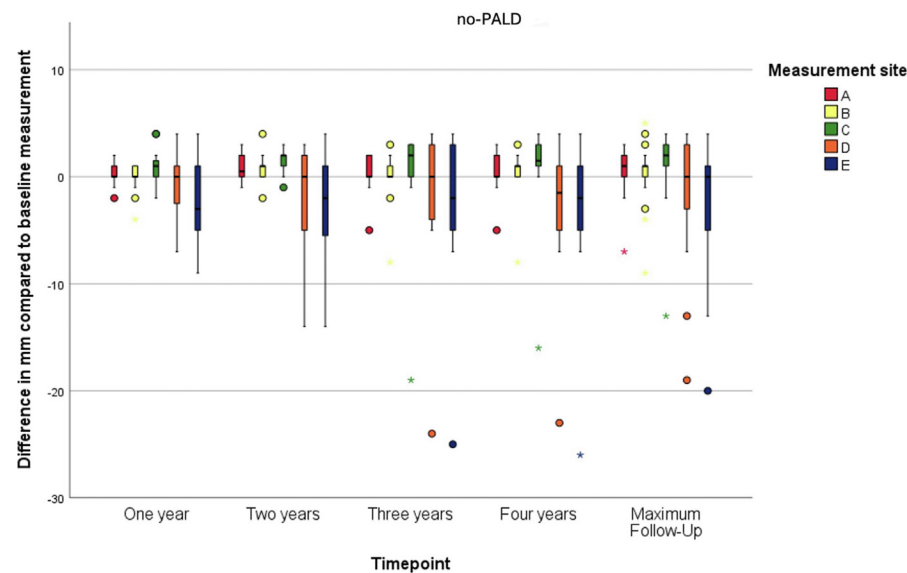


Fig. 4. Boxplots showing difference in mm at 1-, 2-, 3- and 4-year FU and at maximum FU at measurement sites A, B, C, D and E compared to baseline measurements in patients that did not develop PALD.

oversizing. Moreover, the implantation of a TEVAR induces aortic stiffening and alters aortic pressure curves, particularly affecting pulse wave velocity and aortic wall shear stress, among other factors contributing to aortic and cardiac remodeling.⁶

However, oversizing was not associated with higher rates of PALD in our cohort.

Although AND is often viewed as a progression of aneurysmatic disease itself, this explanation does not account for aortic dilation observed in trauma

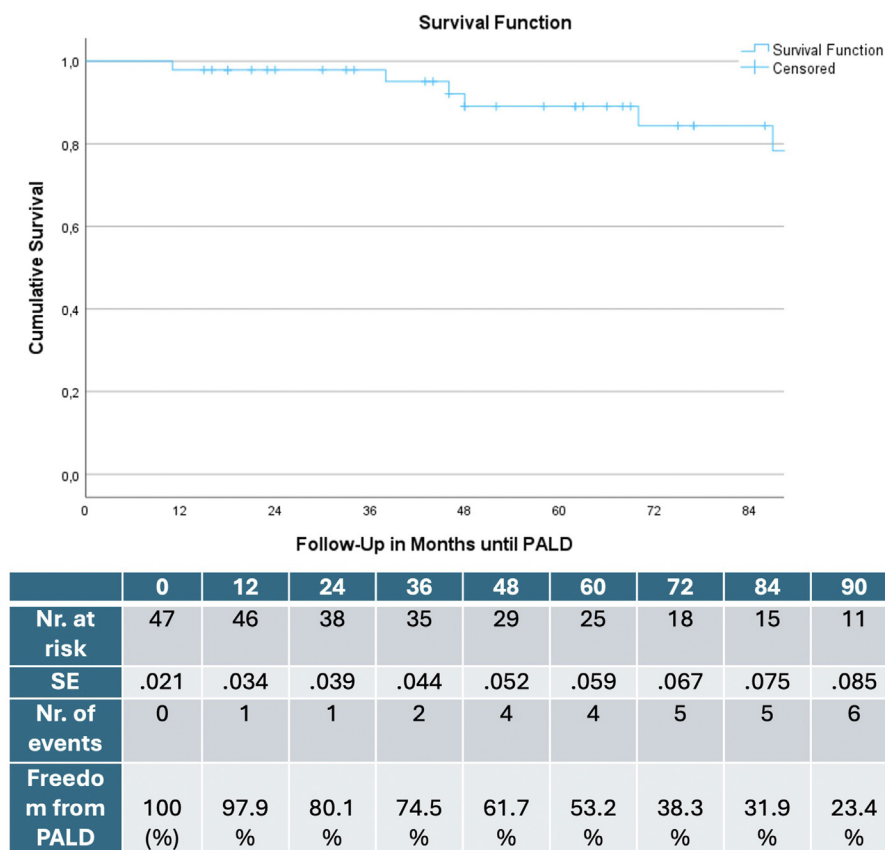


Fig. 5. Kaplan-Meier curve showing proximal aortic landing zone free survival.

patients. Interestingly, in such cases, the segments of the aorta covered by the stent graft tend to dilate, while the native aorta proximal or distal to the stent graft remains unaffected. Notably, similar to a previous study on degenerative aneurysms, the dilation observed in trauma patients did not exhibit a direct significant relation to oversizing.^{2,19}

Notably, although entry flow type IA and consecutive reinterventions at the PAL are described with an incidence ranging between 3 and 30% regarding entry flow type IA,^{8,20,21} they did not occur in our cohort. This may be explained by strict adherence to TEVAR placement in healthy aortic landing zones, as nearly 80% of the cohort had device placement in landing zone II. This aligns with previous reports of a reduced rate of aortic reinterventions and aortic-related adverse events in patients with landing in zone 2 than patients with landing in zone 3, with Mesar et al. reporting freedom from proximal reintervention at 36 months of 96% when landing in zone 2.²² Another explanation may be the fact that more than 70% of patients were omitted because FU imaging to adequately

assess PAL was not available for analysis, which may result in underreporting of PALD, complications as entry flow IA or device migration.

Despite the valuable insights from this study, several limitations should be acknowledged. Firstly, the retrospective nature introduces potential biases, including selection bias and unmeasured confounding variables, which are inherent to observational studies. Secondly, the relatively small sample size may limit the generalizability of these findings to broader patient populations. The inclusion of both acute and chronic dissections introduces heterogeneity into the cohort, which may affect the consistency of outcomes.

Additionally, only patients with sufficient imaging FU were included in the analysis, which may introduce selection bias. Patients who did not attend FU computer tomography imaging may differ in important ways from those who did, and their outcomes remain unknown. The single-center design of the study further limits the external validity of the results, and larger multicenter studies are needed to validate these findings.

CONCLUSION

Despite the occurrence of PALD following TEVAR for TBAD in a notable portion of patients, it did not correlate with increased reintervention rates at the proximal aortic landing zone. Stent graft diameters of >36 mm were the key predictor of PALD, which may be seen as a rather benign imaging finding in TBAD patients without direct impact on patient management.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Wael Ahmad: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Moritz Wegner:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tuna Aras:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation. **Bernhard Dorweiler:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

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