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Original Article

Factors influencing the development of type I endoleak following endovascular aortic repair for abdominal aortic aneurysms

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Abstract

Aim: This study sought to investigate possible anatomical and clinical determinants linked to the occurrence of type I endoleak after endovascular aneurysm repair (EVAR) in patients with abdominal aortic aneurysm (AAA).

Material and Methods: This was a retrospective, single-center cohort study comprising 133 patients who underwent elective EVAR between 2019 and 2024. Patients were categorized according to the presence of type I endoleak (n = 28) or absence (n = 105). Baseline characteristics, comorbidities, and preoperative imaging findings were analyzed. Significant factors influencing development of type I endoleak were identified using multivariable logistic regression, and diagnostic performance was assessed with receiver operating characteristic (ROC) analysis.

Results: Patients who developed type I endoleak were older ($p = 0.048$). They also exhibited significantly larger aortic neck diameters, greater neck angulation, shorter neck lengths, and a higher prevalence of neck calcification. Multivariable analysis confirmed neck diameter (OR = 1.240, $p = 0.001$), neck length (OR = 0.871, $p = 0.002$), neck angulation (OR = 1.077, $p = 0.007$), and calcification ($p = 0.041$) as significant predictive factors. ROC analysis identified 26.5 mm and 58.5° as optimal cut-off values for neck diameter and angulation, respectively.

Conclusion: Adverse proximal neck morphology plays a key role in the development of type I endoleak following EVAR. Careful preoperative assessment of these anatomical features may enhance risk stratification and improve EVAR outcomes.

Keywords: Endovascular aneurysm repair, abdominal aortic aneurysm, type I endoleak, aortic neck anatomy, proximal neck morphology

INTRODUCTION

Abdominal aortic aneurysms (AAA) represent a major vascular condition associated with a substantial risk of mortality, particularly in the event of rupture, and therefore often require timely intervention. Over the last 40 years, endovascular aneurysm repair (EVAR) has been increasingly used as a treatment option, largely because it is less invasive and is linked to reduced perioperative complications and mortality when compared with traditional open surgical repair [1].

The fundamental principle of EVAR is the exclusion of the aneurysmal segment from the systemic circulation through the deployment of an endograft, thereby reducing aneurysm sac pressurization and minimizing the risk of rupture. However, these advantages are accompanied by certain limitations, including the need for long-term imaging surveillance and the potential for device-related complications [2].

Among these complications, endoleaks are considered the most characteristic adverse events following EVAR and are defined as the persistence of blood flow within the aneurysm sac, resulting in inadequate sac decompression [3]. Endoleaks are commonly classified into five distinct types. Among them, type I endoleaks—caused by insufficient sealing at the proximal (type Ia) or distal (type Ib) attachment sites—are regarded as the most clinically significant due to their direct association with an increased risk of rupture [2]. These leaks are generally considered hemodynamically significant, reflecting a failure of effective

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aneurysm exclusion, and frequently require urgent endovascular or surgical intervention [4]. Similarly, a contemporary Turkish series reported that nearly all patients who developed type I endoleaks after EVAR underwent secondary endovascular interventions, emphasizing the clinical importance of early recognition and treatment [5]. Current literature continues to investigate anatomical and patient-related factors influencing EVAR outcomes. In particular, unfavorable proximal neck characteristics, often described as “hostile neck” anatomy, along with increased calcification and vascular tortuosity, are considered important contributors to the development of type I endoleaks [6].

Although several anatomical features have been associated with an increased risk of type I endoleak following EVAR, the relative contribution of individual proximal neck characteristics remains incompletely defined. Furthermore, the threshold values reported in previous studies vary considerably due to differences in patient populations, endograft designs, and imaging methodologies. Consequently, identifying clinically applicable anatomical predictors remains important for optimizing patient selection, procedural planning, and postoperative surveillance.

Based on these considerations, we hypothesized that adverse proximal aortic neck morphology would be independently associated with the development of type Ia endoleak after EVAR. Therefore, this study aimed to evaluate the association between preoperative anatomical characteristics and the occurrence of type Ia endoleak and to identify clinically useful morphological thresholds that may improve preoperative risk stratification.

MATERIAL AND METHODS

Study Population and Design

This study was approved by the Bursa City Hospital Scientific Research Ethics Committee (approval number: 2025-2/5; date: 22 January 2025). The study was conducted retrospectively using anonymized data obtained from hospital medical records without any additional patient intervention or collection of individual informed consent.

A total of 133 adult patients who underwent elective EVAR for AAA at the cardiovascular surgery department of a tertiary referral hospital in Türkiye between August 2019 and December 2024 were included in this single-center, retrospective, observational cohort study.

The inclusion criteria were: (1) age ≥18 years and (2) elective EVAR performed for infrarenal abdominal aortic aneurysm between August 2019 and December 2024. The exclusion criteria were: (1) ruptured abdominal aortic aneurysm, (2) aortic dissection or other acute aortic pathologies, (3) open surgical aneurysm repair, and (4) incomplete clinical or imaging records. Following patient selection, the study population was categorized into the endoleak and non-endoleak groups according to the occurrence of proximal type Ia endoleak during the peri-interventional or follow-up period. All endoleaks included in the analysis were type Ia endoleaks; no patients with isolated type Ib endoleak were identified. The endoleak group comprised 28 patients, while the non-endoleak group comprised 105 patients. Baseline demographic information—including age, sex, height, weight, and body mass index—as well as comorbid conditions such as obesity, hypertension, diabetes mellitus, chronic obstructive pulmonary disease, coronary artery disease, chronic renal failure, congestive heart failure, and peripheral vascular disease were retrieved from the hospital’s electronic medical records system. Patients were not included if they presented with a ruptured abdominal aortic aneurysm, dissection, or any other acute condition; if they required an additional procedure at the same time; if they underwent open aneurysm repair; or if their records were incomplete.

This study was designed and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. No formal sample size calculation was performed because of the retrospective nature of the study. Consecutive eligible patients who underwent elective EVAR during the study period and met the inclusion criteria were included in the analysis.

Pre-interventional Assessment

Pre-procedural radiological imaging was evaluated using 1-mm slice computed tomography angiography (CTA). Intervention for infrarenal AAA was considered when the abdominal aorta reached 55 mm or more in diameter, showed a growth rate of at least 10 mm per year, or when the patient became symptomatic. Aortic neck diameter, aortic neck length, aortic neck angulation, maximum aneurysm diameter, and bilateral iliac artery diameters were measured. In addition, the presence or absence of a conical neck and neck calcification were assessed.

Based on these measurements, suitable proximal and distal landing zones were identified on non-diseased vessel segments. In all patients, the proximal endograft diameter was selected to achieve approximately 20% oversizing relative to the target aortic neck diameter, in accordance with the manufacturer's instructions for use and the institutional standard practice. All measurements were carried out in collaboration with the manufacturer, and the endografts were planned to match these specifications.

Interventional Procedures

Data including the type of anesthesia, medications used, duration of the procedure, procedure-related complications, the need for additional interventions, and post-procedural outcomes (e.g., need for blood transfusion) were recorded.

All interventions were carried out in the angiography suite by a cardiovascular surgeon together with an anesthesiologist, using standard sterile techniques and appropriate anesthesia.

Prior to EVAR, the choice of anesthesia technique for each patient was determined based on the team’s experience and patient characteristics. Both common femoral arteries were used as access sites for endovascular graft delivery. Unfractionated heparin was given at a dose of 100 IU/kg, and after the activated clotting time surpassed 200 seconds, the endograft was advanced in a retrograde manner and deployed in the intended position. Proper graft positioning and complete exclusion of the aneurysm were achieved. In every case, a polyethylene terephthalate–covered Endurant™ II stent graft (Medtronic, Santa Rosa, CA, USA) was used. Completion aortography was performed to confirm graft patency and to check for any endoleaks. Patients were classified as having type Ia endoleak if a proximal endoleak was identified on completion angiography during the index EVAR procedure or during postoperative follow-up, regardless of whether the endoleak resolved after adjunctive endovascular treatment. In contrast, routine adjunctive balloon angioplasty performed solely to optimize proximal graft apposition in the absence of angiographic evidence of type Ia endoleak was not considered an endoleak event.

At the end of the procedure, the common femoral arteries were closed surgically.

Post-interventional Approach

Patients’ lengths of stay in the intensive care unit and hospital were recorded, along with perioperative and late postoperative complications (including endoleak, endograft migration, acute renal failure, and wound infection). Postoperative clinical outcomes, including early and late mortality, were also documented.

The primary study endpoint was the occurrence of type Ia endoleak, classified according to the time of diagnosis as either periprocedural (identified on completion angiography during the index EVAR procedure) or during postoperative follow-up.

Following discharge, all patients underwent routine clinical follow-up at our institution. Contrast-enhanced computed tomography angiography (CTA) was routinely performed during the first postoperative month to evaluate endograft position and detect type Ia endoleaks. Thereafter, postoperative surveillance reflected real-world clinical practice rather than a fixed study protocol. As our institution is a tertiary referral center, a substantial proportion of patients were referred from other cities and subsequently continued their long-term follow-up with their local vascular surgeons. Consequently, imaging beyond the first postoperative month was performed according to the treating physician's clinical judgment or when clinically indicated, rather than at predefined time intervals. Additional CTA examinations were obtained whenever patients presented with symptoms or when graft-related complications were suspected.

The median follow-up duration was 3.4 months (interquartile range, 1–15 months). As this was a retrospective real-world cohort, follow-up duration varied among patients according to referral patterns and clinical indications.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test. Variables showing a normal distribution were expressed as mean ± standard deviation and compared using the independent-samples t-test, whereas non-normally distributed variables were expressed as median (minimum–maximum) and compared using the Mann–Whitney U test. Categorical variables were presented as frequencies and percentages and compared using the Chi-square test or Fisher's exact test, as appropriate. Variables with statistical significance in the univariate analyses were entered into a multivariable logistic regression model to identify independent factors associated with type I endoleak. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the discriminatory performance of significant predictors and to determine the optimal cut-off values. A two-sided p value < 0.05 was considered statistically significant.

RESULTS

A total of 133 patients were included in the study, comprising 28 patients in the endoleak group and 105 patients in the non-endoleak group. Patients in the endoleak group were significantly older compared to the non-endoleak group (74.9±6.8 years vs. 72.3±8.5, $p = 0.048$). There were no statistically significant differences between the groups in terms of gender, height, weight, body mass index, and smoking habit as well as the frequencies of pre-interventional comorbid conditions including obesity, hypertension, diabetes mellitus, chronic obstructive pulmonary disease, coronary artery disease, chronic renal failure, congestive heart failure, and peripheral vascular disease (all p values > 0.05) (Table 1). Among the 28 patients who developed type Ia endoleak, 21 (75.0%) were diagnosed on completion angiography during the index EVAR procedure, whereas 7 (25.0%) were identified during postoperative follow-up.

Review of the pre-procedural imaging showed that, compared with patients without endoleaks, those who developed endoleaks had larger average aortic neck diameters and steeper neck angles, while their aortic neck lengths were shorter on average. In addition, the frequencies of tapered neck and neck calcification were also higher in the endoleak group compared to the non-endoleak group (Table 1).

When peri-interventional data of the patients were assessed, the mean intervention time and the frequency of additional procedure requirement (balloon, extension stent, etc.) were significantly higher in the endoleak group compared to the non-endoleak group. There were no statistically significant differences between the groups in terms of other peri-interventional data, complications, and mortality (Table 2). Among the 28 patients who developed type Ia endoleak, 24 (85.7%) were successfully managed with balloon angioplasty, 3 (10.7%) required proximal aortic extension cuff implantation, and 1 (3.6%) was managed conservatively with imaging surveillance. No patient required conversion to open surgical repair.

A multivariable logistic regression analysis was performed for identifying the significant factors influencing type Ia (proximal) endoleak development by including variables that showed significance in the univariate analysis (age, neck diameter, neck length, neck angle, tapered neck, and neck calcification). The logistic regression model revealed that neck diameter [Odds ratio (OR) = 1.240, 95% Confidence interval (CI): 1.086-1.415, p = 0.001], neck length [OR: 0.871, 95% CI: 0.799-0.950, p = 0.002], neck angle [OR: 1.077, 95% CI: 1.020-1.138, p = 0.007], and neck calcification [OR: 0.152, 95% CI: 0.025-0.925, p = 0.041] were the significant factors influencing type I endoleak development (Table 3). According to the predefined hostile neck criteria, 83 of the 133 patients (62.4%) had hostile neck anatomy. Type Ia endoleak developed in 25 of these patients (30.1%), compared with only 3 of the 50 patients (6.0%) with friendly neck anatomy (p < 0.001) (Table 4).

The efficiencies of neck diameter, neck length, and neck angle in predicting type I endoleak were assessed using ROC analyses. According to the ROC analyses, neck diameter constituted an optimal threshold value of 26.5 mm with 75% sensitivity and 75.2% specificity [Area under the curve (AUC) = 0.771 (0.688-0.854), p < 0.001], neck length constituted an optimal threshold value of 14.5 mm with 39.3% sensitivity and 33.3% specificity [AUC = 0.638 (0.537-0.739) p = 0.0025], and neck angle constituted an optimal threshold value of 58.5° with 71.4% sensitivity and 70.5% specificity [AUC = 0.746 (0.648-0.843), p < 0.001] (Table 5, Figure 1).

Table 1. Baseline demographic and clinical characteristics

Variable	Endoleak group (n = 28)	Non-endoleak group (n = 105)	p value
Age (years)	74.9 ± 6.8	72.3 ± 8.5	0.048*
Gender (male)	25 (89.2%)	99 (94.2%)	0.349
Weight (kg)	87.9 ± 11.4	86.5 ± 11.1	0.573
Height (cm)	172.2 ± 6.4	170.3 ± 6.5	0.177
Body mass index (kg/m²)	29.6 ± 3.9	29.9 ± 3.4	0.849
Obesity	10 (35.7%)	40 (38%)	0.817
Hypertension	9 (32.1%)	46 (43.8%)	0.265
Diabetes mellitus	3 (10.7%)	15 (14.2%)	0.315
COPD	2 (7.1%)	9 (8.5%)	0.807
Coronary artery disease	10 (35.7%)	41 (39%)	0.747
Chronic renal failure	2 (7.1%)	9 (8.5%)	0.807
Congestive heart failure	0 (0%)	6 (5.7%)	0.196
Peripheral vascular disease	5 (%)	22 (20.9%)	0.718
Smoking	11 (39.2%)	38 (36.1%)	0.763
Aortic neck diameter (mm)	28.6 ± 3.3	24.9 ± 4.6	< 0.001*
Aortic neck length (mm)	14.8 ± 5.7	19.5 ± 9.1	0.011*
Aortic neck angle (degree)	61.1 ± 10.1	50.6 ± 11.2	< 0.001*
Widest aneurysm diameter (mm)	76.2 ± 15.7	70.8 ± 12.9	0.104
Tapered neck	6 (21.4%)	7 (6.6%)	0.019*
Neck calcification	7 (25%)	7 (6.6%)	0.005*
LIAD (mm)	15 (9-30)	15 (8-45)	0.788
RIAD (mm)	18 (8-42)	15 (8-30)	0.140

COPD: chronic obstructive pulmonary disease; LIAD: left iliac artery diameter; RIAD: right iliac artery diameter; *: statistically significant

Table 2. Peri-interventional data

Variable	Endoleak group (n = 28)	Non-endoleak group (n = 105)	p value
General anesthesia	9 (32.1%)	29 (27.6%)	0.638
Intraoperative complications	0 (0%)	0 (0%)	1.000
Conversion to open surgery	0 (0%)	0 (0%)	1.000
Thromboembolectomy	1 (3.5%)	3 (2.8%)	0.844
Endograft migration	0 (0%)	0 (0%)	1.000
Acute renal failure	5 (17.8%)	2 (1.9%)	0.439
Wound infection	5 (17.8%)	1 (0.9%)	0.787
Blood transfusion	7 (25%)	4 (3.8%)	0.626
Intervention time (min)	78.5 ± 18.6	61.8 ± 18.5	< 0.001*
Additional procedure (balloon, extension stent, etc.)	24 (85.7%)	25 (23.8%)	< 0.001*
ICU stay (day)	1 (1-7)	1 (1-7)	0.134
Hospital stay (day)	3 (1-9)	3 (1-11)	0.286
In-hospital mortality	1 (3.5%)	1 (0.9%)	0.312
Late mortality	3 (10.7%)	12 (11.4%)	0.915

ICU: Intensive care unit; *: statistically significant

Table 3. Results of multivariable logistic regression analysis

Variable	Beta	SE	Wald	OR	95% CI for expected beta (Upper-Lower)	p value
Age	0.012	0.033	0.125	1.012	0.948-1.079	0.724
Neck diameter	0.215	0.067	10.175	1.240	1.086-1.415	0.001*
Neck length	-0.138	0.044	9.719	0.871	0.799-0.950	0.002*
Neck angle	0.075	0.028	7.209	1.077	1.020-1.138	0.007*
Tapered neck	-0.657	0.772	0.724	0.518	0.114-2.354	0.395
Neck calcification	-1.882	0.920	4.180	0.152	0.025-0.925	0.041*

CI: confidence interval; OR: odds ratio; SE: standard error; *: statistically significant

Table 4. Association between hostile neck anatomy and the development of type Ia endoleak

Variable	Type Ia Endoleak (n = 28)	No Type Ia Endoleak (n = 105)	p value
Hostile neck anatomy, n (%)	25 (89.3)	58 (55.2)	< 0.001
Friendly neck anatomy, n (%)	3 (10.7)	47 (44.8)	

Values are presented as n (%); Comparisons were performed using the Pearson Chi-square test

Table 5. Results of receiver operating characteristic (ROC) curve analysis

Variable	Threshold value	AUC (95% CI)	Sensitivity	Specificity	p value
Neck diameter (mm)	26.5	0.771 (0.688-0.854)	75.0%	75.2%	< 0.001*
Neck length (mm)	14.5	0.638 (0.537-0.739)	39.3%	33.3%	0.025*
Neck angle (degree)	58.5	0.746 (0.648-0.843)	71.4%	70.5%	< 0.001*

AUC: area under the curve; CI: confidence interval; *: statistically significant

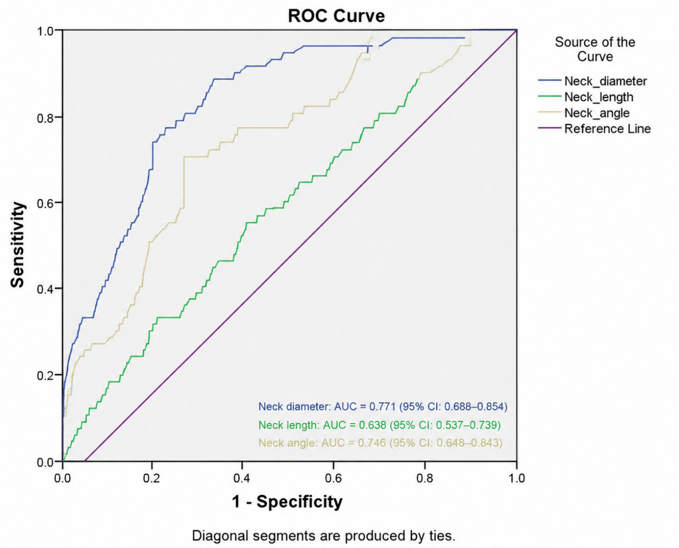

Figure 1. Receiver operating characteristic (ROC) curves for the identified significant factors influencing type I endoleak development

DISCUSSION

This study aimed to evaluate both anatomical and clinical factors that may predict the occurrence of type I endoleak after endovascular aneurysm repair (EVAR) in a modern patient cohort. Our findings underscore the critical role of proximal aortic neck morphology, specifically diameter, length, angulation, and calcification, as significant predictive factors of type I endoleak. These results align with the evolving concept of "hostile neck" anatomy and provide evidence-based thresholds that may refine preoperative risk stratification and patient selection in clinical practice. Consistent with these findings, patients with hostile neck anatomy exhibited a significantly higher incidence of type Ia endoleak than those with friendly neck anatomy, further supporting the importance of comprehensive preoperative anatomical assessment.

The incidence of type I endoleak in our study was 21%, which is slightly higher than the rates reported in some large-scale registries but consistent with cohorts involving a significant proportion of complex neck morphologies [7,8].

In our cohort, this relatively high incidence may be explained by the anatomical characteristics of the study population. According to the predefined hostile neck criteria, 83 of the 133 patients (62.4%) had hostile neck anatomy, and type Ia endoleak developed in 25 of these patients (30.1%), compared with only 3 of 50 patients (6.0%) with friendly neck anatomy (Table 4). Furthermore, approximately 20% proximal endograft oversizing was routinely applied in all patients according to the manufacturer's instructions for use and our institutional practice, making inadequate graft oversizing an unlikely explanation for the observed endoleak rate. The primary challenge in EVAR remains the achievement of a durable proximal seal, particularly when the infrarenal neck deviates from the "friendly" anatomical criteria defined by early device instructions for use (IFU). Our multivariable analysis identified aortic neck diameter as a potent predictive factor of type I endoleak (OR = 1.240, p = 0.001), with a threshold of 26.5 mm. This finding is corroborated by recent evidence suggesting that large neck diameters (>26–28 mm) are associated with increased risks of both early and late sealing failures due to continuous neck dilatation and reduced radial force of the endograft [9,10]. Similar findings have also been reported in a recent study from Türkiye, which demonstrated that patients with large proximal aortic necks experienced less favorable EVAR outcomes compared with those with smaller neck diameters [11]. According to the European Society for Vascular Surgery (ESVS) 2024 Clinical Practice Guidelines, patients with wide aortic necks require more rigorous surveillance and potentially more aggressive sealing strategies, such as the use of EndoAnchors or fenestrated EVAR (F-EVAR), to mitigate the risk of sac expansion [12].

Aortic neck length and angulation also emerged as significant predictive factors in our cohort. An aortic neck shorter than 14.5 mm was linked to the occurrence of type I endoleak, supporting the commonly accepted 10–15 mm range as a practical lower limit for safe standard EVAR. Short necks provide a limited longitudinal landing zone, increasing the susceptibility of the graft to displacement and gutter formation [13]. Furthermore, our identified angulation threshold of 58.5° closely mirrors the widely accepted 60° limit for "hostile" anatomy. Severe infrarenal angulation exerts asymmetrical forces on the endograft, potentially leading to "bird-beaking" and incomplete apposition of the fabric to the aortic wall [14]. Recent meta-analyses have shown that unfavorable proximal neck anatomy markedly elevates the likelihood of type I endoleak compared with more suitable anatomical configurations, and certain studies have even reported up to a threefold rise in the need for secondary procedures [15,16].

The presence of neck calcification was another significant predictive factor of type I endoleak in our multivariable model (p = 0.041). Calcification, particularly when circumferential or involving the sealing zone, impairs the conformability of the endograft and prevents the stent struts from embedding into the aortic wall, thereby creating micro-channels for persistent flow [17]. This observation is supported by the "Hostile Neck Index" proposed in recent literature, which integrates calcification and thrombus load into a comprehensive risk score to predict type I endoleak development [18]. Our results suggest that even in the presence of adequate length and diameter, the quality of the aortic wall—specifically the degree of calcification—must be meticulously evaluated during preoperative planning.

Notably, we observed that patients who developed endoleaks were older on average compared with those without endoleaks (74.9 vs. 72.3 years, p = 0.048). Although age is not a direct cause of endoleak formation, it is often an indicator of more advanced vascular deterioration. This includes greater vessel tortuosity and a reduction in elastic fibers within the aortic wall, both of which may negatively affect the long-term fixation and durability of the endograft [19]. The lack of significant differences in other comorbidities suggests that morphological factors outweigh systemic clinical conditions in determining the immediate success of the endovascular seal.

As emphasized by Chaikof et al. [2], the fundamental challenge of EVAR in the current era is no longer the feasibility of the procedure, but the durability of the exclusion in the face of increasingly complex anatomical presentations.

Despite the insights provided, this study has several limitations. Its retrospective, single-center design may introduce selection bias and limit the generalizability of the findings. Additionally, the sample size, while sufficient for multivariable modeling, may not capture rare clinical events or the long-term impact of sac remodeling beyond the 5-year follow-up.

The relatively short and heterogeneous follow-up duration may have resulted in the underdetection of late type Ia endoleaks. Future prospective, multicenter studies incorporating advanced imaging modalities, such as 4D-CT or computational fluid dynamics, are warranted to further elucidate the hemodynamic triggers of type I endoleak in hostile necks.

CONCLUSION

Adverse proximal neck morphology—characterized by large diameter, short length, severe angulation, and significant calcification—remains the primary driver of type Ia endoleaks following EVAR. Our findings define concrete morphological cut-off values that may help clinicians recognize patients at higher risk, who could be better managed with alternative endovascular strategies or closer follow-up after the procedure. Adherence to established guidelines and careful consideration of "hostile" features are paramount to ensuring the long-term success of endovascular aneurysm repair.

Ethics Committee Approval: This study was approved by the Bursa City Hospital Scientific Research Ethics Committee (approval number: 2025-2/5; date: 22 January 2025).

Patient Consent for Publication: Due to the retrospective design of the study, written informed consent from the participants could not be obtained.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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