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Original Article

Long stents in femoropopliteal interventions: Risk or solution?

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Abstract

Aim: This study aimed to determine the precise influence of total implanted stent length and active smoking on early primary patency among a highly selective cohort of patients undergoing endovascular reconstruction for complex (TASC C/D) femoropopliteal lesions utilizing self-expanding nitinol stents.

Material and Methods: This single-center, retrospective observational cohort analysis included one hundred twenty patients presenting with severe claudication or chronic limb-threatening ischemia (CLTI) who required continuous stenting exceeding five centimeters between the years 2020 and 2025. Primary patency outcomes were statistically evaluated utilizing Kaplan-Meier survival estimates and multivariate Cox proportional hazards regression to adjust for anatomical and clinical confounders.

Results: The average implanted stent length was 12.56 centimeters, yielding a mean early patency of 8.79 months. Multivariate analysis demonstrated no significant linear correlation between continuous stent length and vessel occlusion; however, categorical stratification revealed a statistically significant biphasic paradox ($p = 0.042$). Specifically, mean patency decreased from 9.10 months for stents under 10 centimeters to 7.20 months for stents between 10 and 14.9 centimeters, yet paradoxically rebounded to 10.05 months for extensive scaffolding measuring 15 centimeters or greater. Furthermore, the robust mechanical scaffold overrode early biological risks, as systemic smoking did not significantly compromise early mechanical patency.

Conclusion: Contemporary endovascular outcomes in complex PAD fundamentally challenge the traditional assumption that stent length linearly predicts mechanical failure. The paradoxical superiority of stents ≥ 15 cm reflects the strategic optimization of anatomically healthy landing zones. Extensive mechanical scaffolding that continuously bridges diseased segments from healthy-to-healthy tissue mitigates compliance mismatch and edge-effect restenosis, thereby optimizing early luminal patency.

Keywords: Endovascular procedures; femoropopliteal artery; nitinol stents; peripheral arterial disease; primary patency, vascular scaffolding

INTRODUCTON

In the traditional doctrine of vascular surgery, open autologous bypass—specifically utilizing the great saphenous vein—has long been heralded as the "gold standard" for the revascularization of complex, long-segment peripheral arterial disease (PAD) [1,2]. However, parallel to global demographic aging, an increasing number of patients lack suitable autologous venous conduits due to prior coronary artery bypass grafting (CABG) or varicose vein stripping [2,3].

In the absence of a viable autologous graft, the reliance on synthetic alternatives, such as polytetrafluoroethylene (PTFE) or Dacron, yields suboptimal long-term patency [3,4]. This limitation, coupled with the high physiological toll of open surgical interventions and the challenging nature of surgical revisions upon graft failure, has catalyzed a paradigm shift toward "endovascular-first" strategies [4,5]. With an estimated 200 million symptomatic individuals living with PAD globally, advances in minimally invasive percutaneous techniques have fundamentally altered the therapeutic landscape [5-8].

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Furthermore, the transition to endovascular interventions is strongly driven by patient preference for ambulatory settings, reduced periprocedural morbidity, and accelerated recovery times [9,10].

While the efficacy of endovascular therapy is robustly established for TransAtlantic Inter-Society Consensus (TASC) focal A and B lesions, the optimal management of TASC C and D long-segment occlusions (≥ 15 cm) remains a subject of intense debate [11,12]. Historically, it was a widely accepted consensus that stenting beyond 10 cm in the femoropopliteal segment—an anatomical zone subjected to extreme mechanical forces including flexion, torsion, and elongation—exponentially increased the risk of stent fracture and subsequent in-stent restenosis (ISR) [13,14]. However, the advent of next-generation, highly flexible nitinol stents combined with the procedural principle of "healthy-to-healthy" scaffolding necessitates a critical re-evaluation of this traditional assumption.

The primary clinical problem addressed in this study is the biomechanical challenge and high restenosis rate associated with stenting diffuse, long-segment femoropopliteal lesions. We hypothesized that when treating complex TASC C/D lesions, strictly minimizing stent length and terminating the stent within diseased transitional zones exacerbates compliance mismatch and induces edge restenosis. Conversely, intentionally utilizing longer stents to bridge the entire diseased segment—from healthy proximal to healthy distal tissue—will optimize luminal hemodynamics and significantly improve early patency.

The present study aimed to retrospectively evaluate the real-world outcomes of a contemporary cohort of patients who underwent a 'DCB-first' strategy followed by provisional bare-metal stent (BMS) implantation for complex femoropopliteal lesions. Specifically, this study investigates the impact of total stent length on early-term primary patency and explores the overriding effect of mechanical scaffolding against systemic biological risk factors, such as active smoking.

MATERIAL AND METHODS

Study Design and Patient Population

This retrospective, single-center observational cohort study analyzed the clinical and angiographic data of patients who underwent endovascular revascularization for symptomatic PAD at the Cardiovascular Surgery Department of a tertiary referral center between January 2020 and December 2025. The study protocol was approved by the Alanya Alaaddin Keykubat University Faculty of Medicine Clinical Research Ethics Committee (Decision No: 01-02, Date: 07.January.2026) and was conducted in strict adherence to the principles outlined in the Declaration of Helsinki. A waiver for informed consent was granted due to the retrospective nature of the analysis. The manuscript was prepared in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

To specifically isolate the hemodynamic and biomechanical effects of long-segment stenting and to meticulously eliminate the confounding anatomical variables associated with simpler lesions, a targeted, highly selective cohort of 120 patients was established from an initial pool of 546 consecutive endovascular procedures using a non-probability consecutive sampling method.

Inclusion Criteria: Patients presenting with chronic limb-threatening ischemia (CLTI) or severe claudication (Rutherford category 2–6), possessing de novo TASC C/D complex stenotic or occlusive lesions in the superficial femoral artery (SFA) or popliteal artery, who required provisional (bail-out) stenting.

Exclusion Criteria: Interventions limited exclusively to the iliac or infrapopliteal arteries, treatments managed utilizing pure balloon angioplasty (POBA) or isolated drug-coated balloons (DCB) without stenting, and the deployment of focal stents shorter than 5 cm.

Procedural Protocol and Medical Management

All endovascular procedures were performed in a dedicated angiography suite under local anesthesia. Vascular access was established via the contralateral retrograde crossover, antegrade common femoral, or retrograde popliteal approach, based on lesion morphology. Systemic anticoagulation was achieved with an initial bolus of weight-adjusted intravenous heparin (typically 10,000 IU) to maintain an activated clotting time (ACT) of > 300 seconds.

Lesions were crossed via intraluminal or subintimal tracking utilizing 0.035-inch or 0.018-inch hydrophilic guidewires. In accordance with modern 'leave nothing behind' concepts, our primary therapeutic intent for all target lesions was a 'DCB-first' strategy rather than using standard POBA. Therefore, primary angioplasty was performed using paclitaxel-coated DCBs sized 1:1 to the reference vessel diameter, with prolonged inflation times (average 180 seconds) to optimize antiproliferative drug delivery. The deployment of a self-expanding bare-metal nitinol stent was never a pre-planned combination therapy. Rather, it was strictly utilized as a provisional (bail-out) intervention, indicated only upon mechanical failure of the DCB—specifically, the presence of flow-limiting dissection, residual stenosis > 30%, or significant elastic recoil. Stents were deployed emphasizing complete lesion coverage, extending from healthy proximal to healthy distal tissue (the "healthy-to-healthy" landing zone concept) to mitigate compliance mismatch. Where multiple stents were required, an overlap of at least 0.5 cm to 1.0 cm was maintained. The utilized nitinol platforms included Medtronic Protege/Everflex, Abbott Absolute Pro/Supera, Boston Scientific Epic/Innova, Meril Promesa, and BD LifeStent.

Postoperatively, all patients were prescribed a standardized medical regimen consisting of high-intensity statin therapy (atorvastatin 40 mg or rosuvastatin 20 mg) and dual antiplatelet therapy (DAPT; acetylsalicylic acid 100 mg + clopidogrel 75 mg) for a minimum of three months, followed by lifelong single antiplatelet therapy, unless contraindicated.

Data Collection and Endpoint Definitions

Baseline lesion complexity was retrospectively graded according to the TASC II classification. While a formal quantitative calcification scoring system was not routinely utilized in our historical clinical practice, angiographic reports confirmed that severe target vessel calcification was a universal hallmark of this complex cohort. Due to the retrospective, real-world nature of this study, evaluations were not blinded, and an independent core ultrasound laboratory was not utilized.

The primary endpoint of the study was early-term primary patency, defined as the uninterrupted duration (in months) that the treated vessel remained free from hemodynamically significant binary restenosis (> 50%, based on a peak systolic velocity ratio > 2.4 on duplex ultrasound) or occlusion, without the need for target lesion revascularization (TLR). The variable Total Stent Length (cm) was defined as the cumulative length of all stents deployed within the target lesion, corrected for overlap zones. Patency was evaluated during scheduled follow-up visits via clinical assessment, Ankle-Brachial Index (ABI) measurements, and duplex ultrasound (DUS) or computed tomography angiography (CTA).

Statistical Analysis

Data management and statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and GraphPad Prism (GraphPad Software, San Diego, CA, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed data were presented as mean ± standard deviation (SD), while non-normally distributed data were presented as median with interquartile range (IQR). Categorical variables were expressed as frequencies (n) and percentages (%).

To robustly address potential confounders and mitigate observer bias regarding mechanical patency, a multivariate Cox proportional hazards regression model was constructed. This model incorporated key variables including diabetes mellitus, TASC II lesion complexity, and distal runoff status. Survival curves for primary patency across categorical groups (stent lengths: < 10 cm, 10–14.9 cm, ≥ 15 cm; and smoking status) were generated using the Kaplan-Meier method and compared using the Log-rank test. All reported p values are exact, and a two-sided p-value of <0.05 was considered to indicate statistical significance.

RESULTS

Baseline Demographics and Clinical Characteristics

The study comprised 120 patients with a mean age of 65.8 ± 10.2 years, predominantly male (73.3%, n = 88). The baseline clinical profile was notable for a high burden of atherosclerotic risk factors: active smoking was the most prevalent (75.8%, n = 91), followed by hypertension (49.2%, n = 59), diabetes mellitus (37.5%, n = 45), and coronary artery disease (25.0%, n = 30). Clinically, the majority of patients presented with severe, lifestyle-limiting claudication (Rutherford 2 – 3; 85.0%, n = 102), while 15.0% (n = 18) suffered from CLTI (Rutherford 4–6) (Table 1). Angiographic evaluation confirmed that the cohort consisted exclusively of complex lesions (TASC C: 35.8%, TASC D: 64.2%). Furthermore, consistent with the advanced stage of the disease, severe target vessel calcification was a prevailing angiographic feature across the entire study population.

Procedural Outcomes and Stent Length Dynamics

All 120 target lesions were located within the femoropopliteal arterial segment. Following primary angioplasty with drug-coated balloons, the mean total stent length implanted per patient was 12.56 ± 6.52 cm (median: 11.5 cm; IQR: 8.5 – 15.5 cm; ranging from 5.57 to 40.7 cm). The overall mean early-term primary patency duration for the cohort was 8.79 ± 4.73 months (up to 22.9 months of follow-up). The unit length efficacy was calculated at an average of 0.70 months of primary patency per centimeter of deployed stent. Categorization by stent length yielded 33 patients in the < 10 cm group, 42 patients in the 10 – 14.9 cm group, and 45 patients requiring extensive scaffolding (≥ 15 cm).

Primary Patency and Survival Analysis

A comprehensive multivariate Cox proportional hazards regression model—adjusting for potential confounders including diabetes mellitus, TASC II lesion complexity, and distal runoff status—demonstrated no statistically significant linear association between increasing continuous stent length and a higher risk of early-term patency loss (p = 0.306).

Intriguingly, categorical survival analysis revealed a non-linear, biphasic relationship between stent length and vessel patency. Mean primary patency was 9.10 ± 5.54 months in the < 10 cm cohort. This metric declined to 7.20 ± 3.92 months in the intermediate-length group (10 – 14.9 cm). However, in the extensive stenting group (≥ 15 cm), representing a "Full Metal Jacket" approach, patency paradoxically rebounded to peak at 10.05 ± 5.24 months. Kaplan-Meier survival analysis confirmed that these variations across the three length groups were statistically significant (Log-rank p = 0.042) (Table 2, Figure 1).

Influence of Smoking Status on Mechanical Scaffolding

The impact of systemic biological risk factors on the mechanical stent scaffold was assessed by comparing active smokers (n = 91) to non-smokers (n = 29). The mean patency duration was 8.65 ± 4.56 months for smokers and 9.24 ± 5.30 months for non-smokers (Table 2). Although a marginal numerical reduction was observed in the smoking cohort, Kaplan-Meier analysis indicated no statistically significant difference in early-term primary patency (Log-rank p = 0.563) (Figure 2).

Table 1. Baseline demographic and clinical characteristics of the study cohort

Variables		Total (n = 120)	%
Age (years, Mean ± SD)		65.8 ± 10.2	—
Gender	**Male**	88	73.3
	Female	32	26.7
Comorbidities and risk factors	**Active smoker**	91	75.8
	Hypertension	59	49.2
	Diabetes mellitus	45	37.5
	Coronary artery disease	30	25.0
Clinical presentation	**Claudication (Rutherford 2–3)**	102	85.0
	Chronic limb-threatening ıschemia (Rutherford 4–6)	18	15.0
Anatomic and lesion characteristics	**Femoropopliteal Arteries (Target Vessel)**	120	100.0
	TASC II classification		
	TASC C	43	35.8
	TASC D	77	64.2
	Severe target vessel calcification	120	100.0

Data are presented as mean ± standard deviation (SD) for continuous variables and as frequency (n) and percentage (%) for categorical variables. Severe calcification reflects the prevailing angiographic presentation of the cohort. Abbreviations: CLTI, chronic limb-threatening ıschemia; TASC, TransAtlantic Inter-Society Consensus.

Table 2. Procedural stent parameters and early-term patency outcomes

Procedural variables	Mean ± SD / Median	Range / p-value
Total stent length (cm)	12.56 ± 6.52 (Median: 11.5)	Min: 5.57 – Max: 40.7
Follow-up primary patency (Months)	8.79 ± 4.73	Max up to: 22.9
Patency per centimeter (Months/cm)	0.70	—
Stent length as predictor of patency	—	p = 0.306 (Multivariate Cox)
Patency by stent length strata (Months)	—	p = 0.042 (Log-rank)
< 10 cm stent group (n = 33)	9.10 ± 5.54	
10–14.9 cm stent group (n = 42)	7.20 ± 3.92	
≥ 15 cm extensive stent group (n = 45)	10.05 ± 5.24	
Patency by smoking status (Months)	—	p = 0.563 (Log-rank)
Active smokers (n = 91)	8.65 ± 4.56	
Non-smokers (n = 29)	9.24 ± 5.30	

The relationship between total stent length as a continuous variable and primary patency was evaluated using a multivariate Cox proportional hazards regression model adjusting for diabetes mellitus, TASC II lesion complexity, and distal runoff status. Differences in primary patency between categorical groups were analyzed using Kaplan-Meier survival analysis and the Log-rank test. A p-value < 0.05 was considered statistically significant. The extensive stent group (≥ 15 cm) incorporates the "healthy-to-healthy" tissue coverage approach optimizing laminar hemodynamics. Abbreviations: SD, standard deviation.

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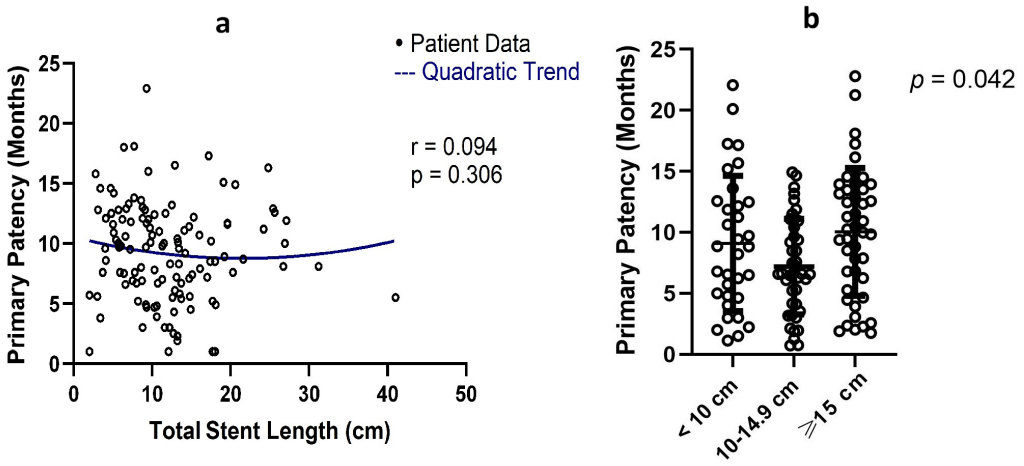
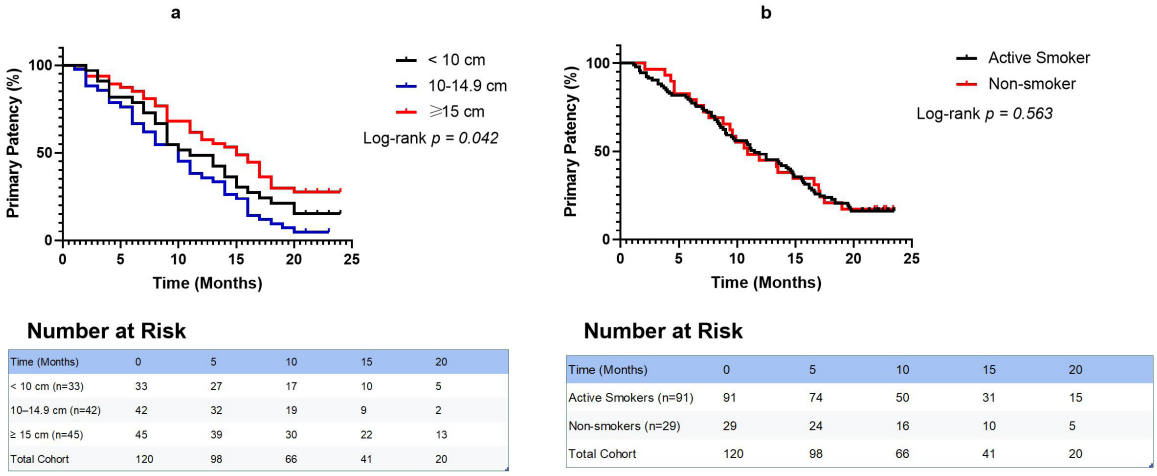


Figure 1. Relationship between total stent length and early-term primary patency; (a) Scatter plot demonstrating the association between continuous total stent length (cm) and primary patency (months). The dashed blue line indicates a quadratic trend, highlighting the absence of a significant linear correlation (r = 0.094, p = 0.306); (b) Categorical distribution of primary patency across three predefined stent length strata: focal/short (< 10 cm), intermediate (10 – 14.9 cm), and extensive (≥ 15 cm) scaffolding. A statistically significant biphasic "U-curve" pattern is observed, characterized by a paradoxical decline in patency within the intermediate group and a robust rebound in the extensive stenting cohort (p = 0.042).



Number at Risk

Time (Months)	0	5	10	15	20
< 10 cm (n=33)	33	27	17	10	5
10–14.9 cm (n=42)	42	32	19	9	2
≥ 15 cm (n=45)	45	39	30	22	13
Total Cohort	120	98	66	41	20

Number at Risk

Time (Months)	0	5	10	15	20
Active Smokers (n=91)	91	74	50	31	15
Non-smokers (n=29)	29	24	16	10	5
Total Cohort	120	98	66	41	20

Figure 2. Kaplan-Meier survival analyses for early-term primary patency; (a) Primary patency survival curves stratified by categorical stent length groups (< 10 cm, 10 – 14.9 cm, and ≥ 15 cm). The extensive stenting group (≥ 15 cm, red line) demonstrates superior patency over time compared to the intermediate group (10 – 14.9 cm, blue line), further confirming the non-linear "Full Metal Jacket" advantage (Log-rank p = 0.042); (b) Primary patency survival curves comparing active smokers (black line) to non-smokers (red line). Systemic active smoking status did not result in a statistically significant difference regarding the early-term mechanical patency of the scaffold (Log-rank p = 0.563). The corresponding numbers of patients at risk at each 5-month interval are provided below the respective graphs.

DISCUSSION

The salient finding of this investigation is that total stent length does not operate as a linear predictor of early-term failure in complex femoropopliteal endovascular interventions. Contrary to historical doctrine, extensive stent scaffolding (≥ 15 cm) demonstrated a paradoxical superiority in early patency compared to intermediate-length stenting (10 – 14.9 cm).

When evaluating revascularization strategies for long-segment (TASC C/D) occlusions, contemporary literature emphasizes the durability of open femoropopliteal bypass grafting, particularly when an autologous vein is utilized. Uhl et al. [2] documented an excellent 1-year primary patency rate of 75.3% for below-knee autologous grafts. However, for patients lacking suitable venous conduits, synthetic bypass grafts yield significantly lower patency rates and higher perioperative morbidity. While heparin-bonded PTFE offers reasonable early results, 5-year secondary patency plummets to roughly 55.6% [2,4,15]. Given these limitations, endovascular therapy—which provides comparable early outcomes—has emerged as a definitive first-line therapy for

many high-risk patients. The TECCO trial elegantly demonstrated that endovascular stenting of the superficial femoral artery halved perioperative complications compared to open surgery while achieving equivalent 24-month primary patency [7]. Importantly, this endovascular-first approach has demonstrated acceptable mid-term durability and limb salvage rates even when extending into complex, multifocal TASC D anatomy [16].

Historically, influential data published by Scheinert et al. [13] established the paradigm that in-stent restenosis rates correlate directly with stent length. While the dip in patency observed in our intermediate cohort (10–14.9 cm) reflects this older concept, the robust patency in the ≥ 15 cm group represents a distinct physiological and strategic divergence. This non-linear phenomenon should not be interpreted as a biologically protective effect of the metal scaffold itself, but rather as a direct reflection of intentional landing zone optimization. When intermediate stents are deployed in extensive disease, they often terminate within transitional zones of diffuse atherosclerotic disease, creating abrupt compliance mismatches and severe mechanical stress—major drivers in the multifactorial etiology of in-stent restenosis, alongside endothelial denudation and chronic inflammation. Conversely, the deployment of extensive stents (≥ 15 cm) is frequently a conscious clinical strategy by operators to bridge the entirety of the diseased segment. By anchoring the stent edges in healthy, compliant proximal and distal tissues ("healthy-to-healthy" landing zones), the operator effectively neutralizes edge turbulence, homogenizes the mechanical stress distributed along the vessel, and restores laminar blood flow [17]. Thus, what might initially appear as "selection bias" towards longer stents in complex lesions is, in fact, a targeted endovascular strategy designed to avoid geographic miss and secure anatomically favorable landing zones, ultimately resulting in superior early patency.

Furthermore, modern nitinol platforms exhibit well-documented radial force and flexibility across large-scale patient-level meta-analyses [18], which appear sufficient to mechanically override early biological thrombogenic triggers. Active smoking is a notoriously aggressive driver of atherosclerosis and PAD progression [14]. Yet, in our cohort, smoking status did not significantly impair early stent patency (Log-rank p = 0.563). While this finding appears to contradict decades of general PAD research, it uniquely reflects the specific dynamics of our heavily diseased, strictly isolated cohort. It strongly implies that early-term patency relies predominantly on the immediate mechanical optimization of the vessel lumen and robust scaffolding rather than systemic biological factors, which tend to manifest their detrimental effects in the longer term. Moreover, the stringent institutional adherence to postoperative dual antiplatelet therapy and high-intensity statin regimens likely played a critical role in stabilizing the endothelium and suppressing early inflammatory cascades across all groups.

Limitations

The present study is subject to several limitations inherent to its single-center, retrospective design. First, a selection bias was intentionally introduced by excluding patients successfully treated with balloon angioplasty alone. Because POBA is generally reserved for lesions with favorable anatomy and minimal calcification, our cohort represents a higher-risk demographic with severely complex anatomical features [19]. Second, the baseline use of paclitaxel-coated balloons introduces a confounding variable regarding the pure mechanical evaluation of the nitinol stents. However, it is crucial to contextualize our procedural algorithm. We adopted a strict 'DCB-first' strategy, bypassing standard POBA to biologically inhibit neointimal hyperplasia as a primary intent. Stenting was exclusively a bail-out procedure necessitated by acute procedural failures, such as flow-limiting dissections or > 30% residual stenosis—factors known to strongly predict DCB failure [20]. As highlighted by Feldman and Klein [21], bail-out stenting is significantly more prevalent in real-world clinical practice than in randomized controlled trials, particularly when managing complex TASC C/D lesions. Furthermore, due to national reimbursement constraints restricting the use of primary drug-eluting stents (DES) in peripheral arteries in our country, this 'DCB-first followed by bail-out bare-metal stenting' algorithm represents our obligatory, optimized real-world strategy for limb salvage. Consequently, while our outcomes reflect the synergistic efficacy of a combined therapy rather than the isolated effect of nitinol, they accurately represent the real-world management of severe PAD where neither isolated balloon angioplasty nor isolated bare-metal stenting would suffice. Third, the study evaluates early-term patency. While this timeframe is critical for assessing the immediate mechanical success of the scaffold, it does not capture the peak incidence of neointimal hyperplasia, which classically manifests between 12 to 24 months post-procedure. Fourth, the lack of an independent core ultrasound laboratory introduces potential observer bias during follow-up evaluations. Finally, our failure to detect the universally accepted negative impact of systemic smoking may represent a Type II error, driven by our specific sample size and the inherent unreliability of retrospective, self-reported smoking histories.

CONCLUSION

Autologous saphenous vein bypass remains unparalleled regarding long-term durability; however, for the vast demographic lacking an adequate venous conduit, endovascular stenting stands as a highly resilient and effective first-line intervention. The findings of this study challenge the historical apprehension regarding long-segment stenting in the femoropopliteal region. Increasing stent length does not precipitate a linear decline in early patency in complex PAD.

Rather, extensive scaffolding (≥ 15 cm) that effectively bridges disease from healthy-to-healthy segments optimizes luminal hemodynamics and mitigates edge-effect restenosis, yielding excellent short-term outcomes. This study highlights the critical importance of landing zone selection: forcing a shorter stent that terminates in diseased tissue may yield worse outcomes than utilizing a longer stent that achieves healthy anchorage. Consequently, the anatomical requirement for a long stent should not deter clinicians from offering minimally invasive endovascular solutions to patients with complex PAD.

Ethics Committee Approval: The study was approved by the Alanya Alaaddin Keykubat University Faculty of Medicine Clinical Research Ethics Committee (Decision No: 01-02, Date: 07.January.2026) and adhered to the principles of the Declaration of Helsinki.

Patient Consent for Publication: A waiver for informed consent was granted due to the retrospective nature of the analysis.

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

Author Contributions: All authors contributed equally to the article.

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