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RESEARCH ARTICLE

Angioarchitectural Determinants of Limb Loss After Endovascular Treatment in Patients with Diabetic Foot Syndrome and Coronary Artery Disease

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Abstract: Background: Diabetic foot syndrome (DFS) combined with ischemic heart disease (IHD) represents a high-risk vascular condition frequently requiring endovascular revascularization. However, clinical outcomes remain heterogeneous, particularly in the presence of diffuse arterial disease.

Objective: To evaluate angioarchitectural and procedural determinants of limb loss after endovascular treatment in patients with DFS and concomitant IHD.

Methods: A retrospective single-center study included 58 patients with DFS and IHD who underwent endovascular intervention between 2015 and 2019. Patients were stratified according to clinical outcome into favorable and unfavorable groups. Angiographic parameters analyzed included number of affected arterial segments, level of involvement, vascular access strategy, and type of intervention (balloon angioplasty alone or combined with stenting). Primary endpoint was major amputation. Secondary endpoints included procedural complications and early mortality.

Results: Unfavorable outcomes occurred in 37.9% of patients. Multi-segment arterial involvement (≥2 segments), extensive disease affecting ≥3 segments, and crossover vascular access were significantly more frequent in the unfavorable group ($p < 0.01$). Combined balloon angioplasty with stenting was required more often in these patients (59.1% vs 33.3%, $p < 0.05$). Stent occlusion, thrombosis, and early restenosis were associated with higher amputation rates. Major amputation occurred in 45.4% of patients with unfavorable outcomes, while early mortality reached 13.6%.

Conclusion: Diffuse angioarchitectural involvement and procedural complexity are strongly associated with limb loss after endovascular treatment in patients with DFS and IHD. Incorporating anatomical severity into preprocedural assessment may improve risk stratification and limb salvage strategies.

Key words: Diabetic foot syndrome; peripheral arterial disease; endovascular treatment; limb loss; angioarchitectural complexity.

INTRODUCTION

Diabetic foot syndrome (DFS) remains one of the most severe and disabling complications of type 2 diabetes mellitus, frequently resulting in major amputation and high long-term mortality. The lifetime risk of foot ulceration in diabetic patients is estimated to exceed 20%, and up to half of these cases are associated with underlying peripheral arterial disease, significantly increasing the probability of limb loss [1,2]. In parallel, many patients with

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advanced DFS present with concomitant ischemic heart disease (IHD), reflecting the systemic and diffuse nature of atherosclerosis in diabetes [3].

Endovascular revascularization has become a cornerstone in the management of chronic limb-threatening ischemia in diabetic patients. Contemporary vascular guidelines emphasize the importance of restoring arterial inflow to promote wound healing and prevent major amputation [4,5]. Balloon angioplasty and stenting of infrainguinal arteries are widely used due to their minimally invasive nature and technical feasibility, even in elderly and multimorbid populations [6]. Reported limb salvage rates after successful revascularization range from 70% to 90%, depending on patient selection and anatomical characteristics of the lesion [5,7].

However, outcomes of endovascular treatment in patients with DFS and concomitant IHD remain heterogeneous. Even technically successful procedures may fail to achieve limb preservation in the presence of diffuse, multi-segment arterial involvement, severe calcification, poor distal runoff, or advanced infectious destruction of the foot [8]. In diabetic patients, atherosclerotic lesions are often long, multilevel, and associated with impaired microcirculation, which limits the functional effect of revascularization despite angiographic success [3,9].

While numerous studies have investigated systemic predictors of unfavorable outcomes, including metabolic decompensation and cardiac dysfunction, the specific role of angioarchitectural characteristics and procedural strategy has received less focused attention [10]. Parameters such as number of affected arterial segments, choice of vascular access, need for combined angioplasty and stenting, and early postprocedural complications may critically influence clinical results but are insufficiently integrated into prognostic assessment models.

The aim of the present study was to evaluate angioarchitectural and procedural determinants of limb loss after endovascular treatment in patients with diabetic foot syndrome and concomitant ischemic heart disease in a single-center cohort.

METHODS

Study Design and Patient Population. This retrospective observational study was conducted at the Republican Specialized Scientific and Practical Medical Center of Surgery named after Academician V. Vakhidov between 2015 and 2019. The analysis included 58 consecutive patients with diabetic foot syndrome (DFS) complicated by lower limb ischemia and concomitant ischemic heart disease (IHD) who underwent endovascular revascularization according to the standard institutional protocol of that period.

Inclusion criteria were confirmed type 2 diabetes mellitus, clinically and instrumentally verified lower limb ischemia (Fontaine stage IIb–IV), presence of ulcerative or necrotic foot lesions (Wagner stages I–V), documented IHD, and availability of complete clinical and procedural data. Patients with terminal heart failure, acute coronary syndrome within 30 days prior to intervention, advanced renal failure requiring dialysis, or incomplete follow-up were excluded.

According to clinical outcome, patients were stratified into two subgroups: favorable outcome — complete wound healing with preservation of limb function; unfavorable outcome - major amputation, persistent non-healing wound, or death within 30 days after intervention.

Clinical and Angiographic Assessment. All patients underwent standardized preoperative evaluation, including clinical examination, laboratory testing (including HbA1c), electrocardiography, and transthoracic echocardiography with assessment of left ventricular ejection fraction.

Severity of limb ischemia was classified according to Fontaine. Extent of tissue destruction was assessed using the Wagner classification.

Angiographic assessment was performed using digital subtraction angiography. Lesions were analyzed with respect to number of affected

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arterial segments (one, two, or ≥3 segments); anatomical level of involvement (femoropopliteal and/or infrapopliteal arteries); presence of subtotal or total occlusions; distal runoff status.

Endovascular Procedures. All interventions were performed in an angiography suite under fluoroscopic guidance. Vascular access was obtained either via ipsilateral antegrade femoral access or via contralateral crossover approach, depending on anatomical feasibility.

Procedural strategies were categorized as: plain transluminal balloon angioplasty (TBA); combined transluminal balloon angioplasty with stenting (TBA + stent).

Stenting was performed in cases of residual stenosis >30%, flow-limiting dissection, or long-segment occlusive disease. Technical success was defined as restoration of antegrade flow with residual stenosis <30% on final angiography.

Outcome Measures. The primary endpoint of the study was major amputation (above ankle level) within the index hospitalization or early postoperative period.

Secondary endpoints included: preservation of anatomical integrity of the limb; preservation of weight-bearing function after minor amputation; early (≤30 days) mortality; procedure-related complications (thrombosis, dissection, early restenosis, stent occlusion, contrast-induced nephropathy).

Statistical Analysis. Continuous variables are presented as mean ± standard deviation. Categorical variables are expressed as absolute numbers and percentages. Comparisons between subgroups were performed using Student's t-test or Mann-Whitney U test for continuous variables, depending on distribution. Categorical variables were compared using the chi-square test or Fisher's exact test where appropriate. A p-value <0.05 was considered statistically significant. Statistical analysis was conducted using SPSS software (IBM SPSS Statistics, version 26.0).

RESULTS

A total of 58 patients with diabetic foot syndrome (DFS) and concomitant ischemic heart disease (IHD) were analyzed. Favorable clinical outcomes were achieved in 36 patients (62.1%), while 22 patients (37.9%) experienced unfavorable outcomes, defined as major amputation, persistent non-healing, or early mortality.

Patients with unfavorable outcomes demonstrated not only a more severe clinical background but also more complex angioarchitectural patterns. Advanced ischemia (Fontaine III–IV) and deep tissue destruction (Wagner IV–V) were significantly more frequent in this subgroup. Similarly, severe metabolic decompensation (HbA1c ≥10%) and reduced left ventricular ejection fraction (<50%) were observed more often among patients who subsequently required major amputation or experienced death. From an anatomical perspective, multi-segment arterial involvement (≥2 segments) and extensive disease affecting three or more segments were markedly more prevalent in the unfavorable outcome group. The need for contralateral crossover access, reflecting proximal occlusive disease, was also significantly higher. Combined procedures involving balloon angioplasty with stenting were required more frequently in patients with adverse outcomes, indicating greater procedural complexity (Table 1).

Table 1. Clinical and Angioarchitectural Characteristics According to Outcome

Parameter	Favorable outcome (n=36)	Unfavorable outcome (n=22)	p-value
Age (years, mean ± SD)	66.1 ± 8.1	70.4 ± 7.6	<0.05
HbA1c ≥10%, n (%)	7 (19.4%)	10 (45.5%)	<0.05
LVEF <50%, n (%)	5 (13.9%)	8 (36.4%)	<0.05
Fontaine III–IV, n (%)	13 (36.1%)	15 (68.2%)	<0.01
Wagner IV–V, n (%)	8 (22.2%)	12 (54.5%)	<0.01
≥2 affected segments, n (%)	13 (36.1%)	16 (72.7%)	<0.01
≥3 affected segments, n (%)	5 (13.9%)	9 (40.9%)	<0.01

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Crossover access, n (%)	9 (25.0%)	14 (63.6%)	<0.01
TBA + stenting, n (%)	12 (33.3%)	13 (59.1%)	<0.05

Procedure-related complications were also more frequent in patients with unfavorable outcomes. Thrombosis of infrapopliteal arteries, early restenosis, and stent occlusion occurred predominantly in cases with multi-level disease and combined endovascular strategies. Notably, stent occlusion was observed almost exclusively in the unfavorable subgroup. Contrast-induced nephropathy developed in a small number of cases, mainly among patients with baseline renal impairment.

Major amputation was performed in 10 patients (45.4%) within the unfavorable subgroup, while no major amputations occurred among patients with favorable outcomes. Early mortality (≤30 days) was registered in 3 patients (13.6%), all belonging to the unfavorable group (Table 2).

Table 2. Procedural Complications and Clinical Outcomes

Outcome / Complication	Favorable outcome (n=36)	Unfavorable outcome (n=22)	p-value
Thrombosis, n (%)	3 (8.3%)	5 (22.7%)	<0.05
Early restenosis (<30 days), n (%)	3 (8.3%)	4 (18.2%)	<0.05
Stent occlusion, n (%)	1 (2.8%)	4 (18.2%)	<0.01
Contrast-induced nephropathy, n (%)	2 (5.6%)	2 (9.1%)	>0.05
Major amputation, n (%)	0	10 (45.4%)	<0.001
Early mortality, n (%)	0	3 (13.6%)	<0.01

Overall, the findings indicate that unfavorable outcomes after endovascular treatment were strongly associated with diffuse multi-segment arterial disease, the need for complex revascularization strategies, and higher procedural complication rates. These angioarchitectural determinants appear to play a critical role in limb prognosis beyond systemic metabolic and cardiac parameters.

DISCUSSION

The present study demonstrates that limb prognosis after endovascular treatment in patients with diabetic foot syndrome (DFS) and concomitant ischemic heart disease (IHD) is strongly influenced by angioarchitectural complexity and procedural characteristics. While systemic factors such as metabolic decompensation and cardiac dysfunction are recognized determinants of adverse outcomes, our data highlight the decisive role of multi-segment arterial involvement, access strategy, and the need for combined balloon angioplasty with stenting.

Diffuse and multilevel arterial disease was significantly associated with limb loss. Patients with involvement of two or more segments, and particularly those with three or more affected segments, showed a markedly higher risk of major amputation. This observation is consistent with previous vascular studies indicating that extensive infrapopliteal and femoropopliteal disease reduces the probability of sustained perfusion even after technically successful revascularization [4,5]. In diabetic patients, arterial lesions are typically long, calcified, and associated with impaired distal runoff, limiting microcirculatory recovery despite restoration of macroscopic flow [3,6].

The need for contralateral crossover access emerged as a surrogate marker of severe proximal occlusive disease. Crossover techniques are generally required when ipsilateral femoral access is not feasible due to common or superficial femoral artery obstruction. Such anatomical patterns reflect a more advanced stage of macroangiopathy and are frequently accompanied by compromised collateral networks [5,7]. Our findings suggest that access strategy itself may serve as an indirect indicator of angioarchitectural severity and, consequently, limb prognosis. The higher frequency of combined transluminal balloon angioplasty with stenting (TBA + stent) in the

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unfavorable subgroup further supports the relationship between procedural complexity and outcome. Stent implantation was more often required in long-segment or calcified lesions, where balloon angioplasty alone was insufficient. However, stent occlusion and early restenosis were substantially more frequent in this subgroup. Previous reports have emphasized that in diabetic populations, restenosis rates after infrapopliteal stenting remain higher than in non-diabetic cohorts, particularly in the presence of diffuse disease and poor distal runoff [6,8]. These mechanisms may explain the limited durability of revascularization in complex anatomical settings.

Procedure-related complications also demonstrated a clear association with unfavorable outcomes. Thrombosis, dissection, and early restenosis occurred more often in patients with multi-segment disease. Although some complications were manageable, stent occlusion and persistent ischemia frequently culminated in major amputation. Similar findings have been described in studies evaluating limb salvage in chronic limb-threatening ischemia, where technical success does not always translate into durable clinical benefit in advanced diabetic vasculopathy [4,9].

Importantly, our data suggest that angioarchitectural determinants act synergistically with systemic factors. Even in the absence of extreme metabolic derangement, extensive anatomical involvement significantly reduced the likelihood of limb preservation. This observation aligns with contemporary concepts emphasizing that diabetic atherosclerosis is characterized not only by systemic inflammation and endothelial dysfunction but also by a distinct morphological phenotype marked by diffuse, distal, and multilevel lesions [3,10]. From a practical perspective, these findings underscore the need for comprehensive preprocedural angiographic assessment beyond simple identification of stenosis severity. Evaluation of lesion length, segmental distribution, and distal runoff should be integrated into decision-making algorithms. In selected patients with extensive three-segment involvement, alternative strategies (including staged procedures, hybrid reconstruction, or early surgical consultation) may be warranted.

The study has limitations. It is retrospective and single-centered, and the sample size is moderate. Microcirculatory parameters were not directly assessed, and long-term patency beyond the early postoperative period was not systematically evaluated. Nevertheless, the homogeneity of the cohort and standardized procedural protocol provide a consistent platform for analyzing anatomical and technical determinants of limb loss.

In summary, unfavorable outcomes after endovascular treatment in patients with DFS and IHD are closely linked to diffuse multi-segment arterial disease, the need for crossover access, combined angioplasty with stenting, and higher rates of procedure-related complications. These angioarchitectural determinants should be incorporated into future stratification models aimed at improving limb salvage in this high-risk population [4,6,9].

CONCLUSION

Angioarchitectural complexity represents a critical determinant of limb prognosis after endovascular treatment in patients with diabetic foot syndrome and concomitant ischemic heart disease. Diffuse multi-segment arterial involvement, particularly affecting two or more vascular segments, the necessity for contralateral crossover access, and the requirement for combined balloon angioplasty with stenting were strongly associated with higher rates of procedural complications, major amputation, and early mortality. These findings indicate that anatomical severity and procedural burden may outweigh isolated technical success in predicting clinical outcomes. Comprehensive preprocedural assessment of lesion distribution, extent, and distal runoff should therefore be integrated into treatment planning to improve limb salvage strategies in this high-risk diabetic population.

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