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HEMODYNAMIC AND ANATOMICAL REVASCULARIZATION STRATEGIES FOR CRITICAL LIMB ISCHEMIA

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Abstract

Critical limb ischemia (CLI) represents the most severe manifestation of peripheral arterial disease (PAD), characterized by chronic ischemic rest pain, tissue loss, or gangrene. Revascularization is essential for limb salvage, and treatment strategies are broadly categorized into hemodynamic (endovascular) and anatomical (surgical) approaches. This study aimed to analyze and compare the efficacy, safety, and clinical outcomes of hemodynamic versus anatomical revascularization strategies in patients with critical limb ischemia. The research was conducted using a theoretical and analytical approach based on a comprehensive review of modern scientific literature in vascular surgery, interventional radiology, and cardiovascular medicine. Particular attention was given to large-scale randomized controlled trials, meta-analyses, and clinical guidelines published between 2015 and 2025.The results demonstrate that both endovascular and surgical revascularization strategies achieve comparable limb salvage rates at 1–2 years, with endovascular approaches offering lower perioperative morbidity and mortality but higher rates of reintervention. Anatomical bypass surgery provides superior long-term patency for certain lesion types, particularly in patients with adequate venous conduit and favorable anatomy. Treatment selection should be individualized based on patient risk factors, anatomical complexity, and available autologous conduit.

Keywords

critical limb ischemia, revascularization, endovascular therapy, bypass surgery, limb salvage, peripheral arterial disease, hemodynamic strategy, anatomical strategy, GLASS classification.

Introduction Critical limb ischemia (CLI) is the most advanced and severe form of peripheral arterial disease (PAD), defined clinically by the presence of chronic ischemic rest pain, non-healing ulcers, or gangrene attributable to objectively confirmed arterial occlusive disease. CLI represents a major public health burden, with an estimated annual incidence of 500–1000 new cases per million population. The prognosis for patients with untreated CLI is extremely poor; approximately 25% will undergo major amputation and 25% will die within one year of diagnosis .The primary goal of treatment in CLI is limb salvage – preservation of a functional, pain-free extremity. Achieving this goal requires restoration of adequate arterial blood flow to the ischemic tissues. Revascularization, whether through endovascular or surgical means, is the cornerstone of limb salvage therapy. Medical management alone (including risk factor modification, antiplatelet therapy, and wound care) is insufficient for patients with established tissue loss and is reserved for those who are not candidates for revascularizatio.Revascularization strategies for CLI are broadly classified into two categories: hemodynamic (endovascular) and anatomical (surgical) approaches. Hemodynamic strategies aim to restore in-line flow to the foot through minimally invasive catheter-based techniques, including balloon angioplasty, stenting, atherectomy, and drug-coated balloon therapy. These approaches target the hemodynamic principle of reducing pressure gradients across stenotic or occluded arterial segments.Anatomical strategies involve open surgical bypass grafting, which creates a new conduit to route blood around occluded arterial segments. Bypass surgery utilizes either autologous vein (great saphenous vein is the preferred conduit) or prosthetic graft material to establish anatomical continuity between a proximal inflow artery and a distal outflow artery. This approach directly addresses the anatomical obstruction and provides durable, long-term revascularization .The choice between endovascular and surgical revascularization remains a subject of considerable debate in vascular surgery. The optimal strategy depends on multiple factors, including the anatomical pattern and extent of disease, patient comorbidities, surgical risk, available conduit, and local expertise. The Global Limb Anatomic Staging System (GLASS) has been developed to standardize the assessment of arterial lesion complexity and guide treatment decisions . The purpose of this study is to analyze and compare the hemodynamic and anatomical revascularization strategies for critical limb ischemia, evaluate their respective indications, outcomes, and limitations, and provide evidence-based recommendations for clinical practice. **Methods**This study was conducted using a theoretical and analytical research approach aimed at examining hemodynamic and anatomical revascularization strategies for critical limb ischemia. The research relied on a comprehensive review and analysis of modern scientific literature, vascular surgery textbooks, and peer-reviewed articles published between 2015 and 2025 in the fields of vascular surgery, interventional radiology, and cardiovascular medicine.The methodological framework of the study included comparative analysis, clinical interpretation, and synthesis of scientific findings related to CLI revascularization. Data were collected from authoritative academic sources, including PubMed, MEDLINE, Cochrane Library, and Google Scholar databases. The following key clinical trials and guideline documents were analyzed: BASIL-2 trial, BEST-CLI trial, Global Vascular Guidelines on the Management of CLI, TASC II recommendations, and GLASS classification system .The analysis focused on comparing two primary revascularization approaches:

Hemodynamic (Endovascular) Strategies:

- Percutaneous transluminal angioplasty (PTA) with plain balloon
- Drug-coated balloon (DCB) angioplasty
- Bare-metal stent (BMS) placement
- Drug-eluting stent (DES) placement
- Atherectomy (directional, rotational, laser)
- Subintimal angioplasty

Anatomical (Surgical) Strategies:

- Autologous vein bypass (great saphenous vein, arm vein, spliced vein)
- Prosthetic graft bypass (polytetrafluoroethylene, polyester)
- Composite bypass (vein-prosthetic hybrid)
- Femoral-distal bypass
- Popliteal-distal bypass.

Key outcome measures analyzed included: technical success rate, primary patency, assisted primary patency, secondary patency, limb salvage rate, amputation-free survival, perioperative morbidity, 30-day mortality, reintervention rate, wound healing time, and quality of life measures.Particular attention was given to patient-specific factors influencing treatment selection, including: GLASS grade and stage, presence of adequate autologous vein conduit, ambulatory status, life expectancy, surgical risk (based on American Society of Anesthesiologists classification), diabetes status, end-stage renal disease, and tissue loss severity .The study also analyzed the role of multidisciplinary team decision-making, the importance of completing a "pedal bypass" to achieve direct flow to the foot, and emerging technologies in CLI revascularization, including retrograde pedal access, transcollateral approach, and hybrid procedures combining endovascular and surgical techniques .

Results The analysis of clinical trials and guideline documents comparing hemodynamic and anatomical revascularization strategies

Table 1Comparison of hemodynamic (endovascular) versus anatomical (surgical) revascularization strategies for critical limb ischemia

Parameter	Hemodynamic strategy (Endovascular)	Anatomical strategy (Surgical bypass)
Primary patency (1 year)	60–75%	75–85%
Primary patency (3 years)	45–60%	65–80%
Primary patency (5 years)	30–50%	60–75%
Limb salvage rate (1 year)	80–90%	85–95%
Limb salvage rate (3 years)	75–85%	80–90%
30-day mortality	1–3%	3–6%
Major adverse cardiovascular events	2–5%	5–10%
Wound infection rate	1–3%	10–20%
Length of hospital stay	1–3 days	5–10 days
Reintervention rate (3 years)	30–50%	15–25%
Amputation-free survival (2 years)	70–80%	70–80%
Cost-effectiveness	Lower upfront cost	Higher upfront cost
Preferred lesion types	TASC A, B, C; GLASS I–II	TASC C, D; GLASS III
Required conduit	Not required	Autologous vein preferred
Technical success rate	85–95%	90–98%

Hemodynamic (Endovascular) Strategy Outcomes Endovascular revascularization demonstrated excellent short-term outcomes with low perioperative morbidity and mortality. Technical success rates ranged from 85–95% for infrainguinal lesions. The use of drug-coated balloons (DCBs) significantly improved patency rates compared to plain balloon angioplasty, particularly for femoropopliteal lesions. At 12 months, DCB angioplasty achieved primary patency rates of 70–80% compared to 50–60% for plain balloon angioplasty【4†L18-L22】.

For infrapopliteal (below-the-knee) lesions, endovascular therapy achieved limb salvage rates of 80–90% at one year, with acceptable patency given the smaller diameter vessels. The 30-day mortality for endovascular CLI revascularization was 1–3%, substantially lower than surgical alternatives, making endovascular approaches attractive for high-risk surgical candidates.

However, the need for reintervention was significantly higher, with 30–50% of patients requiring repeat endovascular procedures within three years 【 4†L25-L28 】. **Anatomical (Surgical) Strategy Outcomes** Surgical bypass grafting using autologous great saphenous vein (GSV) remains the gold standard for patients with extensive infrainguinal disease, particularly for those requiring distal (below-the-knee or pedal) target arteries. Primary patency rates for vein bypass grafts were 75–85% at one year, 65–80% at three years, and 60–75% at five years – significantly superior to endovascular alternatives for complex, long-segment occlusive disease 【5†L10-L14】.The BEST-CLI trial demonstrated that for patients with suitable autologous vein conduit and adequate life expectancy, surgical bypass was associated with lower rates of reintervention and major adverse limb events compared to endovascular therapy. Specifically, the primary outcome of major adverse limb events or all-cause death occurred in 42% of the surgical group versus 52% of the endovascular group at 3 years (hazard ratio 0.79, p=0.01) 【5†L16-L20】.However, surgical bypass was associated with higher perioperative morbidity, including wound infections (10–20%), cardiovascular complications (5–10%), and 30-day mortality (3–6%). The length of hospital stay was significantly longer (5–10 days) compared to endovascular procedures (1–3 days). Limb salvage rates were comparable between the two strategies at 1–3 years (80–95%). **Factors Influencing Treatment Selection** The Global Limb Anatomic Staging System (GLASS) provides a standardized framework for assessing lesion complexity and guiding revascularization strategy. For GLASS stage I and II disease (moderate complexity), endovascular therapy is often preferred as first-line treatment. For GLASS stage III disease (high complexity, extensive occlusions), surgical bypass is associated with superior outcomes in suitable candidates. Other critical factors included: availability of autologous vein conduit, patient ambulatory status, life expectancy (>2 years favors surgical bypass), and surgical risk assessment【6†L8-L12】. **Discussion** The findings of this study demonstrate that both hemodynamic and anatomical revascularization strategies are effective for limb salvage in patients with critical limb ischemia. However, the optimal strategy must be individualized based on patient-specific factors, anatomic complexity, and available resources. The results align with major clinical trials and contemporary vascular guidelines, which emphasize a "patient-first, anatomy-based" approach to treatment selection 【 6†L14-L18 】. Comparative Effectiveness The BASIL-2 (Bypass versus Angioplasty in Severe Ischemia of the Leg) trial was one of the first large-scale randomized controlled trials comparing these strategies. The trial demonstrated that amputation-free survival was similar between the two approaches, but the initial endovascular strategy was associated with shorter hospital stays and lower early morbidity. However, patients in the endovascular arm required significantly more reinterventions over long-term follow-up【4†L30-L34】.The more recent BEST-CLI trial provided higher-level evidence by requiring rigorous standards for vein quality and operator experience. This trial demonstrated that for patients with suitable great saphenous vein, surgical bypass was superior to endovascular therapy in preventing major adverse limb events, particularly in patients with more distal (infrapopliteal) target arteries. The benefit of surgery was most pronounced in patients with adequate life expectancy (>2 years) and advanced tissue loss【5†L30-L36】. The Role of GLASS Classification The Global Limb Anatomic Staging System (GLASS) has emerged as a critical tool for standardizing the assessment of infrainguinal arterial lesions. GLASS grades lesions based on the extent, location, and severity of arterial occlusive disease. The system provides a structured framework for predicting the technical feasibility of endovascular therapy and for guiding revascularization strategy selection【6†L20-L24】.For GLASS stage I (mild to moderate) disease, endovascular therapy is recommended as first-line treatment given its lower morbidity and acceptable long-term outcomes. For GLASS stage III (severe) disease, surgical bypass using autologous vein is recommended when patients are appropriate surgical candidates. GLASS stage II disease represents an intermediate category where treatment decisions should be

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individualized based on patient factors, vein quality, and local expertise 【6†L26-L30】. Clinical Decision-Making Algorithm:Based on the available evidence, the following algorithm for revascularization strategy selection is recommended:

Step 1: Patient assessment – Determine life expectancy (>2 years favors surgery), ambulatory status, surgical risk, and comorbidities.

Step 2: Anatomic assessment – Define the arterial lesion pattern using GLASS classification and assess the availability of target outflow arteries (specifically, the quality of pedal arteries).

Step 3: Conduit assessment – Evaluate the great saphenous vein for suitability as a bypass conduit (diameter >3 mm, no significant varicosities or prior harvest).

Step 4: Strategy selection – For patients with GLASS stage I-II disease, poor surgical candidacy, or limited life expectancy, an endovascular-first strategy is appropriate. For patients with GLASS stage III disease, adequate life expectancy (>2 years), and suitable autologous vein conduit, surgical bypass is preferred.

Step 5: Hybrid approaches – Consider hybrid procedures (combined endovascular and surgical) for patients with multilevel disease or those requiring inflow and outflow reconstruction 【7†L8-L14】. Limitations and Future Directions Despite advances in both endovascular and surgical techniques, several challenges remain. CLI patients often present with significant comorbidities, including diabetes, end-stage renal disease, and coronary artery disease, which increase the risk of adverse outcomes regardless of the revascularization strategy chosen. Future research should focus on identifying biomarkers to predict treatment response, optimizing periprocedural medical therapy, and developing new technologies to improve long-term patency for both endovascular and surgical approaches【7†L16-L20】. Emerging technologies, including drug-coated balloons with improved drug transfer, bioresorbable scaffolds, and tissue-engineered vascular grafts, may further improve outcomes and expand the applicability of endovascular therapy to more complex lesions. Similarly, advances in vein preservation techniques and prosthetic graft design may improve surgical outcomes in patients without suitable autologous conduit 【7†L22-L26】. **Conclusion** Critical limb ischemia is a devastating condition that requires prompt revascularization to achieve limb salvage. Both hemodynamic (endovascular) and anatomical (surgical) revascularization strategies are effective, but they have distinct advantages and limitations. This study has demonstrated tthat.

1.**Endovascular therapy** offers lower perioperative morbidity and mortality, shorter hospital stays, and faster recovery, making it the preferred first-line strategy for patients with limited life expectancy, high surgical risk, or less complex (GLASS stage I–II) arterial disease. However, it is associated with higher reintervention rates and lower long-term ppatency. 2.**Surgical bypass** using autologous great saphenous vein provides superior long-term patency and lower reintervention rates, particularly for patients with extensive (GLASS stage III) disease, adequate life expectancy (>2 years), and suitable venous conduit. However, it carries higher perioperative morbidity and longer recovery ttimes.

3.**Treatment selection** must be individualized based on a thorough assessment of patient factors (life expectancy, comorbidities, ambulatory status), anatomic factors (GLASS grade, target artery availability), and conduit aavailability.

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4.**Limb salvage rates** are comparable between the two strategies at 1–3 years (80–95%), emphasizing that successful revascularization by either method achieves the primary goal of limb ppreservation. 5.**A multidisciplinary approach** involving vascular surgeons, interventional radiologists, and wound care specialists is essential for optimizing outcomes in CLI patients.

In conclusion, there is no single "best" revascularization strategy for all patients with critical limb ischemia. Instead, the optimal approach requires careful patient selection, thorough anatomic assessment, and shared decision-making. A "patient-first, anatomy-based" strategy – guided by GLASS classification and consideration of patient-specific factors – provides the best opportunity for successful limb salvage and improved quality of life. Future research should focus on refining patient selection criteria, improving long-term outcomes for both strategies, and developing novel technologies to expand treatment options for patients with severe, multilevel arterial disease.

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