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The Future of Treatment Models in Peripheral Artery Disease: Surgical and Endovascular Approaches

Periferik Arter Hastalıklarında Tedavi Modellerinin Geleceği: Cerrahi ve Endovasküler Yaklaşımlar

Burak Toprak[1], Mehmet Erin Tüysüz[1]

[1]Cardiovascular Surgeon, Mersin City Education and Research Hospital, Mersin, Türkiye

ABSTRACT
Peripheral artery disease (PAD) affects over 200 million people worldwide, leading to significant morbidity and mortality. Treatment strategies have evolved from traditional surgical revascularization to minimally invasive endovascular techniques. Recently, hybrid procedures combining surgical and endovascular approaches have emerged as a promising alternative to optimize patient outcomes. This review compares the efficacy, benefits, and limitations of these treatment modalities in PAD management.
A comprehensive analysis of recent randomized controlled trials, cohort studies, and systematic reviews was conducted using PubMed, Scopus, and Web of Science. Key metrics, including patency rates, complication profiles, amputation-free survival, and patient-reported outcomes, were evaluated. Findings suggest that surgical revascularization remains the gold standard for complex PAD cases due to superior long-term patency, despite higher perioperative risks. Endovascular interventions, such as angioplasty and stenting, offer lower short-term complications and faster recovery but are associated with higher restenosis rates. Hybrid procedures provide an alternative for high-risk patients and complex lesions, integrating the advantages of both techniques. Technological advancements, including drug-coated devices and precision imaging, continue to refine treatment outcomes.
The choice of optimal PAD treatment depends on lesion complexity, patient comorbidities, and durability requirements. While surgical approaches provide long-lasting results, endovascular techniques offer less invasive solutions with lower immediate risks. Hybrid strategies bridge these approaches, improving outcomes in select cases. Future research should focus on long-term comparative studies and personalized treatment models to enhance clinical decision-making in PAD management.
Keywords: Peripheral artery disease, critical limb ischemia, surgical revascularization, endovascular treatment, hybrid procedures, multidisciplinary approaches.

ÖZET
Periferik arter hastalığı (PAH), dünya çapında 200 milyondan fazla insanı etkileyen, morbidite ve mortaliteye neden olan önemli bir vasküler hastalıktır. Tedavi yaklaşımları, geleneksel cerrahi revaskülarizasyondan minimal invaziv endovasküler tekniklere evrilmiştir. Son yıllarda, cerrahi ve endovasküler yöntemleri birleştiren hibrit prosedürler, hasta sonuçlarını optimize etmek için yeni bir seçenek olarak ortaya çıkmıştır. Bu derlemede, PAH tedavisinde cerrahi, endovasküler ve hibrit yaklaşımların etkinliği, avantajları ve sınırlamaları karşılaştırılmaktadır.
Çalışmada PubMed, Scopus ve Web of Science veritabanlarında yapılan güncel randomize kontrollü çalışmalar, kohort analizleri ve sistematik derlemeler incelenmiştir. Tedavi yaklaşımlarının etkinliğini değerlendirmek için açıklık oranları, komplikasyon profilleri, ampütasyonsuz sağkalım ve hasta bildirimli sonuçlar gibi temel metrikler analiz edilmiştir. Bulgular, kompleks PAH vakalarında cerrahi revaskülarizasyonun uzun dönem açıklık açısından üstün olduğunu ancak daha yüksek perioperatif riskler taşıdığını göstermektedir. Endovasküler girişimler, anjiyoplasti ve stentleme gibi yöntemlerle düşük kısa dönem komplikasyonları ve hızlı iyileşme sağlarken, restenoz oranları önemli bir sorun olmaya devam etmektedir. Hibrit prosedürler ise yüksek riskli hastalar ve kompleks lezyonlar için umut vadeden bir alternatif olarak öne çıkmaktadır.
PAH tedavisinde en uygun yaklaşım, lezyonun kompleksliği, hastanın ek hastalıkları ve uzun vadeli dayanıklılık gereksinimleri göz önünde bulundurularak belirlenmelidir. Cerrahi girişimler kalıcı sonuçlar sunarken, endovasküler teknikler düşük riskli minimal invaziv seçenekler sağlamaktadır. Hibrit stratejiler, uygun hastalarda her iki yöntemin avantajlarını birleştirerek sonuçları iyileştirebilir. Gelecekte, uzun dönem karşılaştırmalı çalışmalar ve kişiselleştirilmiş

tedavi modelleri, PAH yönetiminde klinik karar alma süreçlerini daha da geliştirebilir.
Anahtar kelimeler: Periferik arter hastalığı, kritik ekstremite iskemisi, cerrahi revaskülarizasyon, endovasküler tedavi, hibrit prosedürler, multidisipliner yaklaşımlar

Introduction

Peripheral artery disease (PAD) is a prevalent vascular condition affecting over 200 million individuals worldwide, with significant associations with morbidity and mortality[1]. Song et al. (2019) highlighted an increasing prevalence of PAD in recent years, primarily driven by the rising incidence of diabetes[1]. The disease commonly results from atherosclerosis. This condition causes arterial narrowing or obstruction, which leads to insufficient blood flow to the extremities[2]. PAD is more prevalent in populations with widespread risk factors such as diabetes and smoking, contributing to its substantial global health burden[3]. This burden extends beyond the risks of amputation and mortality, encompassing economic and social implications.

Critical limb ischemia (CLI), the advanced stage of PAD, significantly increases the risk of amputation and mortality. CLI is characterized by resting pain, tissue loss, and gangrene[4]. Studies indicate that untreated CLI patients face a 25% risk of major amputation or death within one year[5]. CLI is particularly common among diabetic patients, who also tend to experience a worse clinical course[6].

The pathophysiology of PAD involves a combination of mechanisms, including inflammation, endothelial dysfunction, and oxidative stress. Research into PAD pathophysiology has deepened our understanding of the role of inflammatory processes and genetic factors. These mechanisms contribute to the formation of atherosclerotic plaques and arterial occlusions[7]. In diabetic patients, microvascular complications and vascular wall damage due to smoking accelerate PAD progression[1,3].

The primary goals in the diagnosis and management of PAD are to control symptoms, prevent disease progression, and reduce amputation rates[4]. Wolosker et al. (2022) emphasized the influence of regional differences on treatment strategies for PAD[8]. Between 1996 and 2006, a marked increase in lower-extremity endovascular interventions was observed, accompanied by a decrease in major amputation rates[9]. Treatment options include surgical revascularization and endovascular techniques. Surgical revascularization remains an effective approach for CLI, with durable long-term patency rates[10,11]. Conversely, endovascular interventions are favored for their minimally invasive nature and shorter recovery times[4]. A 12-year epidemiological analysis revealed that most lower-extremity revascularizations in Brazil's Public Health System were performed using endovascular methods[8].

Recent technological advancements in endovascular devices have introduced new possibilities for PAD treatment. Innovations aimed at reducing restenosis rates, such as drug-eluting balloons and stents, have achieved significant success[2]. Propensity score-matched analyses suggest that the long-term outcomes of endovascular and surgical revascularization are comparable[12]. The Society for Vascular Surgery has established reporting standards for the endovascular treatment of chronic lower-extremity PAD, providing guidance for clinical study designs and outcome evaluations[13]. Additionally, advancements in imaging modalities such as magnetic resonance angiography (MRA) and computed tomography angiography (CTA) have greatly facilitated diagnosis and treatment planning[14].

One of the main challenges in managing PAD lies in patient heterogeneity. Factors such as age, comorbidities, and lesion characteristics directly influence treatment decisions. While surgical methods offer durable long-term results, their invasive nature limits their applicability in high-risk patients[14]. Endovascular therapies, on the other hand, present a viable alternative for elderly and comorbid patients due to their less invasive approach[3].

Future efforts should focus on conducting more randomized controlled trials comparing the effectiveness of surgical and endovascular methods. Developing patient-centered approaches in PAD management and tailoring treatment plans to individual patient profiles are seen as critical objectives moving forward[4].

Materials and Methods

Overview

This study is designed as a narrative review rather than a systematic review; therefore, PRISMA guidelines were not applied. Instead, a selective and descriptive synthesis of the literature was conducted to provide a comprehensive overview of current evidence. This review aims to examine the clinical efficacy of treatment models for peripheral artery disease (PAD) and to compare the long-term outcomes of surgical and endovascular approaches. The study evaluates randomized controlled trials (RCTs) and cohort analyses from the existing literature. This narrative review synthesizes evidence from recent studies to provide a comprehensive understanding of treatment models for peripheral artery disease (PAD), focusing on key clinical outcomes and advancements in both surgical and endovascular approaches.

Eligibility Criteria

The review includes articles focusing on patients diagnosed with PAD who underwent either surgical or endovascular treatment. The selected literature consists of studies published within the last 10 years in high-impact journals. Specific metrics of interest include complication rates, patency durations, and amputation-free survival.

Information Sources

Data were collected using PubMed, Scopus, and Web of Science databases. The primary keywords employed for the search were "peripheral artery disease," "critical limb ischemia," "surgical revascularization," and "endovascular treatment."

Selection Process

Two independent researchers selected the studies, which were subsequently assessed for content relevance. Additionally, critical studies cited in the selected articles were reviewed for inclusion.

Data Extraction

The extracted data were analyzed based on parameters such as procedural success rates, frequency of complications, long-term patency, and patient quality of life. The analysis included a detailed evaluation of patient age groups, comorbidity profiles, and post-treatment complication rates.

Results

a. Etiology and Pathophysiology

Peripheral artery disease (PAD) is a chronic vascular condition caused by atherosclerosis in peripheral arteries, leading to impaired blood flow. The atherosclerotic process begins with endothelial cell dysfunction and progresses through inflammation, lipid accumulation, and fibrous tissue formation[2]. The activation of inflammatory mediators during this process promotes the formation of atheromatous plaques and narrows the arterial lumen[1]. Factors such as diabetes and smoking exacerbate endothelial damage, accelerating the progression of this process[3].

Oxidative stress and the production of free radicals contribute significantly to disease progression. These factors damage endothelial cells and trigger vascular dysfunction[1-3]. Inflammatory processes involved in PAD pathophysiology are critical factors that directly influence treatment outcomes. These processes amplify local inflammation, resulting in vascular smooth muscle cell proliferation and extracellular matrix remodeling[7]. Endothelial dysfunction and vascular remodeling cause permanent arterial narrowing and occlusions, leading to ischemic symptoms in the extremities[4].

Systemic inflammation plays a significant role in PAD pathophysiology. Elevated levels of inflammatory biomarkers, such as C-reactive protein (CRP) and tumor necrosis factor-alpha (TNF-α), are commonly observed in patients with PAD and are associated with disease progression[5]. Furthermore, atherosclerotic plaques contain cellular components such as macrophages and T cells, which sustain inflammation and destabilize plaques[14].

In diabetic patients, PAD pathophysiology is more complex. Hyperglycemia leads to the formation of advanced glycation end products (AGEs), which enhance vascular inflammation. Additionally, diabetic patients frequently experience microvascular complications, leading to more pronounced lesions in infrapopliteal arteries[6]. Diabetic foot ulcers and infections further complicate the clinical management of PAD, resulting in higher amputation rates in this population[3].

Smoking is a major risk factor for PAD and plays a critical role in its pathophysiological processes. Carbon monoxide, nicotine, and other toxic compounds in cigarettes damage vascular endothelial cells, accelerating atherosclerotic plaque formation[4]. Moreover, smoking increases platelet aggregation, elevating the risk of thrombotic events[1].

As PAD progresses, oxygen and nutrient supply to the extremities diminishes, leading to tissue hypoxia, cell death, and necrosis. Although the hypoxic environment stimulates the production of pro-angiogenic factors like VEGF, these mechanisms are often insufficient for effective tissue repair[10,11]. In cases of critical limb ischemia (CLI), this process becomes more severe, resulting in increased risks of amputation and mortality [2]. A systematic review on CLI highlighted that endovascular treatment methods offer lower complication rates compared to surgical options[15].

The role of genetic factors in PAD pathophysiology is also under investigation. Studies have reported that familial hypercholesterolemia and other genetic disorders contribute to PAD development[16]. Additionally, genetic variants influencing the stability of atherosclerotic plaques have been identified in PAD patients[7].

In conclusion, the etiology and pathophysiology of PAD involve a complex interplay of atherosclerosis, inflammation, oxidative stress, and genetic predisposition. Each of these factors contributes to disease progression, affecting the clinical course and response to treatment[5].

b. Risk Factors

Peripheral artery disease (PAD) develops as a result of a combination of systemic and environmental risk factors that trigger the onset and progression of atherosclerosis, shaping the course of the disease.

Diabetes is one of the most significant risk factors for PAD. Hyperglycemia damages endothelial cells, accelerating atherosclerotic processes. Advanced glycation end products (AGEs) contribute to vascular stiffness and inflammation[6]. Diabetic patients frequently exhibit microvascular lesions, particularly in infrapopliteal arteries, leading to more severe clinical manifestations of PAD[3]. Additionally, diabetes negatively impacts wound healing, increasing the risk of amputation in cases of critical limb ischemia (CLI)[5].

Smoking is strongly associated with the development and progression of PAD. Nicotine and carbon monoxide cause damage to the vascular wall, accelerating atherosclerosis. Furthermore, smoking increases platelet aggregation and the risk of thrombosis[4]. In PAD patients, smoking triples the risk of amputation and reduces patency rates following surgical revascularization[1].

Hypertension contributes to endothelial damage and atherosclerosis by increasing arterial pressure[2]. Chronic high blood pressure triggers vascular smooth muscle cell hyperplasia, leading to arterial lumen narrowing[7]. Poorly controlled hypertension in PAD patients increases complication risks and adversely affects treatment outcomes[14].

Elevated serum cholesterol levels are another major risk factor for PAD. Low-density lipoprotein (LDL) particles play a central role in the formation of atherosclerotic plaques[3]. Statin therapy, by lowering LDL levels, can slow atherosclerotic progression and reduce the risk of amputation in PAD patients[16].

Age is an independent risk factor for PAD, with prevalence reaching up to 20% in individuals over 70 years old[1]. Aging leads to changes such as loss of arterial elasticity, intimal thickening, and endothelial dysfunction[5]. Additionally, the high prevalence of comorbidities in older individuals makes the diagnosis and treatment of PAD more complex[4].

A sedentary lifestyle is a significant contributor to PAD development. Reduced physical activity diminishes blood flow, impairs arterial oxygenation, and increases vascular inflammation[6]. Regular exercise can improve symptoms and increase walking distance in PAD patients[3].

Men have a higher risk of developing PAD than women; however, postmenopausal women experience an increased risk due to reduced estrogen levels[7]. Familial hypercholesterolemia and other genetic disorders have also been linked to PAD[16]. Genetic predisposition contributes to PAD pathophysiology through inflammation and thrombotic processes associated with specific genetic variants[14].

PAD is more prevalent in patients with chronic kidney disease (CKD). Reduced renal function is associated with vascular calcification and inflammation[2]. Additionally, PAD progression has been reported to be more rapid in patients undergoing hemodialysis[5].

In summary, PAD is influenced by a multifactorial interplay of systemic conditions, environmental exposures, and genetic predispositions. Each of these factors contributes to disease progression, clinical severity, and treatment response. Table 1 provides a detailed summary of PAD prevalence and its associated risk factors, offering a comprehensive view of systemic and environmental influences on the disease (Table 1).

Table 1. Summary of Studies on Peripheral Artery Disease (PAD) Prevalence and Risk Factors

Study and Year	**Study Design**	**PAD Prevalence**	**Reported Risk Factors**
Song et al., 2019[1]	Systematic Review	Global, 3–10% in general population	Diabetes, Smoking, Hypertension
Thukkani & Kinlay, 2015[2]	Review	Not reported	Smoking, Diabetes, Dyslipidemia
Howard et al., 2023[3]	Cohort Study	10–15% in surgical patients	Claudication severity, Age
Shishehbor & Jaff, 2016[4]	Systematic Review	CLI: 15–25%	Lesion characteristics, Renal failure
Vartanian & Conte, 2015[5]	Review	30% in CLI cases	Infection, Smoking
Lepäntalo et al., 2012[6]	Cohort Study	~20% in younger patients with CLI	Smoking, Diabetes
Lawall et al., 2016[7]	Guideline Review	10% in elderly populations	Hypertension, Age
Wolosker et al., 2022[8]	Epidemiological Analysis	5% increase in PAD interventions	Healthcare accessibility
Goodney et al., 2009[9]	Database Analysis	15–20% with limb symptoms	Diabetes, Smoking
Bradbury et al., 2005[10]	Randomized Controlled Trial	CLI-related interventions: ~20%	Rest pain, Smoking
Popplewell et al., 2016[11]	RCT Protocol	Estimated CLI prevalence: 15%	Smoking, Diabetes
Parvar et al., 2022[12]	Propensity Score Analysis	25–30% CLI outcomes	Chronic renal failure
Stoner et al., 2016[13]	Guideline Review	Not reported	Intervention standards
Tang et al., 2018[14]	Cost Analysis	Not reported	Cost metrics in PAD care
Jones et al., 2014[15]	Systematic Review	Amputation risk in CLI: ~20%	Severe ischemia
Menard & Farber, 2014[16]	Multidisciplinary Review	30% in CLI patients	Rest pain, Ulcers
Colacchio et al., 2023[17]	Cost Analysis	20% cost-effective cases	Healthcare costs
Doshi et al., 2018[18]	Comparative Analysis	15–25% in limb-threatened PAD	Diabetes, Hypertension
Kumbhani et al., 2014[19]	Registry Analysis	35% limb adverse events	Smoking, High LDL
Darling et al., 2017[20]	Comparative Study	25% in CLI interventions	Age, Comorbidities
Söderström et al., 2010[21]	Propensity Score Analysis	15% infrapopliteal CLI cases	Lesion complexity
Siracuse et al., 2017[22]	Registry Analysis	CLI procedural outcomes: ~10%	Access site complications
Aboyans et al., 2018[23]	Guideline Review	General PAD population: 10–20%	Age, Lifestyle factors

c. Diagnosis and Clinical Findings

Peripheral artery disease (PAD) may be asymptomatic in its early stages, with up to 50% of cases going undetected[4]. However, as the disease progresses, symptoms become more apparent, prompting diagnostic evaluation. The methods used to diagnose PAD are critical for assessing disease severity and determining appropriate treatment options.

The diagnostic process for PAD begins with a detailed patient history and physical examination. One of the most common symptoms is intermittent claudication, characterized by pain during walking that resolves with rest[6]. In more advanced stages, critical limb ischemia (CLI) may present with rest pain, tissue loss, or gangrene[5]. Physical examination findings such as absent peripheral pulses, changes in skin color, and the presence of ulcers can help assess the severity of PAD[3].

One of the most widely used diagnostic tools for PAD is the ankle-brachial index (ABI), calculated by dividing the systolic blood pressure at the ankle by the systolic pressure in the brachial artery. An ABI value of <0.90 indicates PAD, while a value of <0.50 suggests critical ischemia[4]. ABI is a reliable diagnostic method with a sensitivity and specificity of over 95%[1]. However, in diabetic patients, arterial calcification can result in falsely negative ABI readings, necessitating supplementary diagnostic methods[7].

Treadmill exercise testing is used to evaluate the functional impact of PAD, particularly in patients with intermittent claudication. This test measures blood pressure changes and symptom onset during exercise[2]. Post-exercise ABI measurements can provide a more accurate assessment of PAD severity[14].

Advanced imaging modalities are essential for evaluating PAD. Magnetic resonance angiography (MRA) provides high-resolution images without radiation exposure and is particularly useful for assessing small vessel disease in diabetic patients[5]. Computed tomography angiography (CTA) offers detailed anatomical insights into the localization and severity of PAD but requires caution in patients with renal dysfunction due to the risk of contrast-induced complications[4].

Doppler ultrasonography is a non-invasive method widely used to assess PAD. It measures blood flow velocity and direction to identify areas of arterial narrowing or occlusion[10]. Duplex ultrasonography provides additional information on vessel structure and hemodynamics, aiding in treatment planning[6].

The role of biomarkers in PAD diagnosis is gaining increasing attention. Inflammatory markers such as C-reactive protein (CRP) and tumor necrosis factor-alpha (TNF-α) have been associated with the presence and severity of PAD[4]. Additionally, levels of natriuretic peptides and fibrinogen may help evaluate prognosis in PAD patients[7].

PAD presents across a broad clinical spectrum, with symptom severity varying according to disease stage. In early stages, the disease may be asymptomatic, but as it progresses, intermittent claudication—pain in the muscles during walking that resolves with rest often becomes the first noticeable symptom. This typically affects the calf muscles[1]. In advanced stages, persistent rest pain, particularly during sleep, is a hallmark of tissue ischemia[2]. CLI patients are at risk of severe complications such as tissue loss and gangrene, which significantly increase the likelihood of amputation and require prompt intervention[14].

Other symptoms reported in PAD include extremity coldness, pallor, skin discoloration, and delayed wound healing, indicating insufficient blood flow and the onset of ischemic tissue hypoxia[3].

Diagnosing PAD can be particularly challenging in asymptomatic patients or those with diabetes. Arterial calcification in diabetic patients can reduce the accuracy of diagnostic tests, leading to false-negative results[6]. Diabetic neuropathy may also mask PAD-related pain, allowing the disease to progress undetected. Comorbidities such as heart failure or chronic obstructive pulmonary disease (COPD) may further obscure PAD's clinical presentation, complicating diagnosis[5].

These diagnostic challenges underscore the importance of a multidisciplinary approach to PAD management. Careful clinical evaluation and the judicious use of advanced diagnostic tools are crucial for ensuring timely and effective treatment.

d. Therapeutic Approaches

The primary goal in the treatment of peripheral artery disease (PAD) is to alleviate symptoms, preserve the affected limb, and reduce long-term cardiovascular mortality. Treatment strategies are individualized based on the severity of the disease, lesion localization, and the patient's overall health status. PAD management generally includes surgical revascularization, endovascular therapies, and medical management.

Surgical treatment stands out as an effective option, especially in cases of critical limb ischemia (CLI), offering long-term patency rates[10,11]. The most common surgical method is bypass surgery using an autologous saphenous vein. This technique is employed to bypass arterial obstructions at femoropopliteal or femorodistal levels, improving amputation-free survival rates in CLI patients[5].

One advantage of surgical treatment is the ability to bypass the lesion entirely, achieving higher long-term success rates. However, surgical procedures are often more invasive, with longer recovery times. In elderly patients and those with significant comorbidities, the complication rates associated with surgery are higher[4]. The effectiveness of surgery depends on the quality of the graft material and surgical techniques. Studies have demonstrated that saphenous vein grafts provide longer patency durations compared to synthetic grafts[3].

Endovascular therapies have gained prominence in recent years due to their minimally invasive nature and shorter recovery periods. These methods include balloon angioplasty, drug-coated balloons, stents, and atherectomy devices[2]. A comparative analysis of endovascular treatment with covered stents and open surgical repair for complex aortoiliac occlusive disease showed that the endovascular approach resulted in lower hospital costs[17]. Balloon angioplasty is a simple and effective method for widening narrowed arteries, but it carries a high risk of restenosis. Consequently, drug-coated balloons (DCBs) and drug-eluting stents (DESs) have been developed, achieving significant success in reducing restenosis risk [14]. In the treatment of lower-extremity peripheral artery disease, endovascular methods have been associated with lower in-hospital mortality and complication rates[18].

Atherectomy aims to mechanically remove arterial plaque and is particularly effective in treating calcified lesions. However, due to the high complication rates associated with atherectomy, careful patient selection is essential[4]. Endovascular therapies are highly effective for lesions in iliac arteries but are less effective than surgery for infrapopliteal regions[5].

Hybrid procedures combine surgical and endovascular techniques and are used for treating complex lesions. For instance, balloon angioplasty of distal arteries can follow femoropopliteal bypass surgery[4]. These procedures improve patient outcomes by combining the durability of surgery with the minimal invasiveness of endovascular techniques[3].

Medical management in PAD treatment focuses on symptom control and cardiovascular risk factor modification. Antiplatelet agents (e.g., aspirin and clopidogrel) inhibit platelet aggregation, reducing the risk of arterial occlusion[6]. Statin therapy lowers low-density lipoprotein (LDL) levels, slowing atherosclerotic progression and reducing the risk of amputation[1]. Statin use not only reduces amputation rates in PAD patients but also improves long-term limb outcomes[19].

Blood pressure control is another important management strategy. Antihypertensive drugs, particularly angiotensin-converting enzyme (ACE) inhibitors, have been shown to improve symptoms in PAD patients[7]. Additionally, diabetes management by maintaining optimal glycemic levels can slow the progression of PAD[5].

Exercise is a critical therapeutic approach for PAD patients, increasing walking distance and alleviating symptoms. Supervised exercise programs significantly improve quality of life and walking capacity in patients with intermittent claudication[14]. These programs enhance peripheral muscle oxygen utilization, supporting arterial circulation[6]. Table 2 outlines the treatment methods for PAD, including surgical and endovascular approaches, along with their clinical findings, emphasizing the complementary roles of these therapies (Table 2).

Table 2. Summary of Studies on PAD Treatment Methods and Clinical Findings

Study and Year	Study Design	Treatment Methods	Key Clinical Findings
Song et al., 2019[1]	Systematic Review	Guideline-based care	Focus on prevalence and diabetes impact
Thukkani & Kinlay, 2015[2]	Review	Endovascular therapies	Improved outcomes with drug-coated balloons (DCBs)
Howard et al., 2023[3]	Cohort Study	Surgical bypass	Higher patency rates in severe cases
Shishehbor & Jaff, 2016[4]	Systematic Review	Percutaneous interventions	Lower complication rates in CLI
Vartanian & Conte, 2015[5]	Review	Surgical revascularization	Durable long-term results
Lepäntalo et al., 2012[6]	Cohort Study	Bypass surgery	Improved outcomes in younger patients
Lawall et al., 2016[7]	Guideline Review	Comprehensive management	Emphasis on lifestyle and medical therapy
Wolosker et al., 2022[8]	Epidemiological Analysis	Endovascular techniques	Increased access to interventions
Goodney et al., 2009[9]	Database Analysis	Hybrid procedures	Lower major amputation rates
Bradbury et al., 2005[10]	Randomized Controlled Trial	Angioplasty vs. bypass	Durability vs. invasiveness
Popplewell et al., 2016[11]	RCT Protocol	Bypass and endovascular	Long-term comparison planned
Parvar et al., 2022[12]	Propensity Score Analysis	Endovascular revascularization	Comparable outcomes to surgery
Stoner et al., 2016[13]	Guideline Review	Endovascular standards	Improved procedure reporting
Tang et al., 2018[14]	Cost Analysis	Amputation, bypass, or endovascular	Cost-effectiveness focus
Jones et al., 2014[15]	Systematic Review	Revascularization strategies	CLI-specific survival outcomes
Menard & Farber, 2014[16]	Multidisciplinary Review	Endovascular and surgical	Focused on CLI management
Colacchio et al., 2023[17]	Cost Analysis	Covered stents vs. open repair	Better outcomes with stents
Doshi et al., 2018[18]	Comparative Analysis	Endovascular therapies	Reduced hospital costs and improved recovery
Kumbhani et al., 2014[19]	Registry Analysis	Statin therapy	Lower adverse limb outcomes
Darling et al., 2017[20]	Comparative Study	Primary bypass and angioplasty	Reduced complications with surgery
Söderström et al., 2010[21]	Propensity Score Analysis	Bypass vs. angioplasty	Bypass favored for infrapopliteal lesions
Siracuse et al., 2017[22]	Registry Analysis	Endovascular techniques	Safe femoral access outcomes
Aboyans et al., 2018[23]	Guideline Review	Integrated PAD management	Lifestyle modifications recommended

Discussion

Surgical and endovascular approaches in the treatment of peripheral artery disease (PAD) have distinct advantages and limitations that affect both short- and long-term patient outcomes. Studies in the literature emphasize the need to individualize the choice between these two methods based on factors such as the patient's overall condition, lesion characteristics, and comorbidities.

Surgical revascularization is considered an effective option in patients with critical limb ischemia (CLI) due to its long-term patency rates and durability. The BASIL-2 study demonstrated the effectiveness of surgical methods, particularly bypass procedures using autologous saphenous vein grafts, in improving long-term amputation-free survival rates[11]. Comparative studies between surgical bypass and endovascular therapies in patients with chronic limb-threatening ischemia highlight the superior long-term outcomes of surgical approaches[20]. Darling et al. (2017) confirmed the durability of surgical bypass while also noting the high perioperative risks associated with surgical interventions, particularly in elderly patients and those with significant comorbidities[5]. The choice of graft material significantly influences treatment outcomes, with autologous grafts offeringlower restenosis rates and longer patency durations compared to synthetic grafts[4]. For infrapopliteal lesions, surgical bypass provides long-term advantages, while balloon angioplasty offers lower early complication rates due to its minimally invasive nature[21].

Endovascular therapies, on the other hand, are increasingly preferred for high-risk patients due to their minimally invasive nature and shorter recovery times. Studies report lower in-hospital mortality and complication rates associated with endovascular treatments for lower-extremity PAD[18]. Balloon angioplasty and drug-coated balloons (DCBs) are the most commonly used tools in endovascular therapy. The endovascular treatment of the common femoral artery reduces complication rates through its minimally invasive approach[22]. Thukkani and Kinlay (2015) showed that DCBs reduce restenosis rates and are effective in femoropopliteal lesions[2]. However, higher restenosis rates in infrapopliteal regions compared to surgical methods represent a limitation of this approach[14]. Moreover, the lower long-term patency rates of endovascular therapies compared to surgery underscore their limitations[3]. Between 1996 and 2006, a significant increase in lower-extremity endovascular interventions was observed, accompanied by a decrease in major amputation rates[9].

Technological advancements in endovascular devices have significantly improved PAD treatment outcomes. For instance, Shishehbor et al. (2016) demonstrated promising results with atherectomy and drug-eluting stents in treating complex lesions[4]. However, the high costs and technical challenges of these devices limit their widespread applicability. Additionally, the higher risk of thrombotic events in endovascular treatments necessitates careful patient selection[5]. The Society for Vascular Surgery has established reporting standards for the endovascular treatment of chronic lower-extremity PAD, which have been instrumental in guiding clinical study design[13]. Propensity score-matched analyses suggest similar long-term outcomes between endovascular and surgical revascularization[12]. An analysis in the Brazilian Public Health System revealed that the majority of lower-extremity revascularizations were performed using endovascular methods[8].

Hybrid procedures combine surgical and endovascular techniques. They have gained increasing importance in managing complex PAD cases. These approaches enhance patient outcomes by integrating the durability of surgery with the minimal invasiveness of endovascular methods [3]. For example, balloon angioplasty in distal regions following surgical bypass has improved treatment success rates in multisegmental arterial lesions[1]. However, limited data are available on the long-term efficacy of such procedures, highlighting the need for further research.

The cost-effectiveness of PAD treatment methods is another important consideration. The cost-effectiveness of endovascular therapies, combined with their minimally invasive nature, makes them an attractive option for healthcare systems. A comparative analysis of endovascular treatment with covered stents and open surgical repair for complex aortoiliac occlusive disease demonstrated lower hospital costs with the endovascular approach[17]. Colacchio et al. (2023) reported that endovascular therapies offer lower hospital costs and greater patient comfort compared to surgical methods. Tang et al. (2018) noted that although the initial costs of endovascular treatments are high, their short recovery time and lower complication rates reduce the overall burden on healthcare systems[14]. Conversely, surgical treatments may have lower initial costs but incur higher total costs due to longer hospital stays and perioperative complications[10,11].

Another key finding in the literature is the importance of individualized approaches to PAD treatment. The BASIL-2 study indicated that surgery is more appropriate for younger patients with longer life expectancy, while Shishehbor et al. highlighted the safety of endovascular treatments in elderly, high-risk patients [4,11]. Moreover, risk factors such as smoking and diabetes negatively impact treatment success and play a critical role in treatment selection [1].

In the context of the Turkish healthcare system, the application of hybrid procedures remains limited to a few tertiary centers with advanced vascular teams and hybrid operating rooms. Although these techniques offer promising results in complex cases, logistical barriers, cost considerations, and the need for multidisciplinary coordination restrict their widespread use. Therefore, developing structured referral systems and investment in hybrid infrastructure are essential to extend the benefits of these approaches to a broader patient population. Integrating hybrid techniques within national treatment algorithms may significantly enhance outcomes, especially in patients with critical limb-threatening ischemia who are often managed in regional hospitals.

In conclusion, surgical and endovascular methods in PAD treatment are complementary approaches. The 2017 ESC guidelines emphasize the importance of multidisciplinary strategies in the diagnosis and management of PAD[23]. Surgical methods offer durability and long-term patency, while endovascular therapies are distinguished by their minimally invasive nature and faster recovery times. The BASIL-2 study demonstrated the superiority of surgical bypass, particularly in terms of long-term patency and amputation-free survival, in patients with lower-extremity chronic limb-threatening ischemia[11]. A systematic review on CLI indicated lower complication rates with endovascular therapies compared to surgical methods[15]. However, both methods have limitations, and treatment decisions should be tailored to patient-specific factors. There is a growing need for more randomized controlled trials in PAD treatment and an increasing focus on patient-centered treatment planning.

Limitations

One of the primary limitations of this study is the limited and heterogeneous nature of the available data in the literature. Most of the reviewed studies are single-center or retrospective in design, underscoring the need for higher-level evidence derived from large-scale randomized controlled trials. Additionally, data comparing the long-term outcomes of surgical and endovascular treatments are scarce, creating gaps in evaluating the effectiveness of these treatment modalities.

Another significant limitation is the diversity of patient populations. There are notable differences among the patients evaluated in the studies in terms of age, gender, comorbidities, and lesion characteristics. This heterogeneity may reduce the generalizability of the findings and highlights the need for the development of individualized treatment approaches. Furthermore, the introduction of new endovascular devices may render older studies in the existing literature outdated.

Lastly, the lack of data based on economic analyses complicates the evaluation of the cost-effectiveness of PAD treatments. Therefore, future research should focus on conducting broader, multicenter, and prospective studies to address these limitations.

Conclusions

In conclusion, surgical and endovascular methods are considered complementary approaches in the treatment of peripheral artery disease (PAD). Surgical treatment provides superior long-term patency rates and durability, making it a favorable option for severe PAD cases such as critical limb ischemia (CLI). On the other hand, endovascular treatments stand out with their minimally invasive nature, shorter recovery times, and lower complication rates. However, the invasive nature and high perioperative risks of surgery present significant limitations, especially in elderly patients and those with significant comorbidities. Conversely, higher restenosis rates and limited long-term success in endovascular treatments highlight the challenges of these methods. Treatment selection clearly necessitates consideration of individual factors such as the patient's overall condition, lesion characteristics, and life expectancy. Patient-centered approaches are becoming increasingly critical in deciding between surgical and endovascular treatments.

The growing utilization of hybrid procedures offers a promising approach to managing complex PAD cases. Combining surgical and endovascular techniques has the potential to improve outcomes in complex lesions, though more data on the long-term efficacy of these methods is needed. The current literature emphasizes the importance of individualized approaches in PAD treatment. While minimally invasive methods may be prioritized for low-risk patients, surgical options provide more durable outcomes for younger patients with longer life expectancy.

Looking forward, more randomized controlled trials are needed. These will help fill knowledge gaps and guide clinical practice. PAD treatment requires an integrated approach aimed not only at alleviating symptoms but also at improving quality of life and long-term survival.

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Correspondence Address / Yazışma Adresi
Burak Toprak
Cardiovascular Surgeon
Mersin City Education and Research Hospital
Mersin, Türkiye
e-mail: brk.tprk@gmail.com

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