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Advances in Polyester Vascular Grafts: Design, Performance, Biocompatibility, and Emerging Innovations

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Abstract: Cardiovascular diseases (CVDs) are the leading cause of death globally, underscoring the importance of surgical interventions such as vascular grafts in restoring blood flow and managing vascular diseases. Polyester vascular grafts have been a staple in CVD treatment for over six decades due to their mechanical durability and ease of handling. However, issues like thrombogenicity, compliance mismatch, and susceptibility to infection persist, prompting the need for innovation in graft design and material properties. The review focuses on examining the evolution of polyester vascular grafts, addressing limitations, and exploring advanced modifications to improve clinical outcomes. This review aims to evaluate the development, clinical applications, and material advancements associated with polyester vascular grafts. It will analyze their mechanical and biological performance, compare them with other graft types, and explore potential improvements in design and surface modification to address current limitations. While the review does not provide specific details on the literature search strategy, it likely involved synthesizing existing research from clinical studies, material science advancements, and innovations in graft design. Key references are included to support the comparative analysis of polyester grafts and emerging technologies. Polyester vascular grafts, especially in large-diameter applications, offer long-term patency and mechanical reliability. However, they face challenges such as infection, thrombogenicity, and mechanical mismatch with native vessels. Recent advancements, including hybrid grafts, drug-eluting coatings, and electrospun nanofiber scaffolds, are explored for their potential to enhance graft integration, biocompatibility, and resistance to microbial colonization. Furthermore, emerging technologies like personalized 3D-printed grafts and smart grafts with biosensors hold promise for future vascular therapies. Polyester vascular grafts remain crucial in vascular surgery, yet significant room for improvement exists. Future advancements, particularly in hybrid, bioactive, and smart grafts, could address current challenges, offering more personalized and effective solutions for complex vascular conditions. The ongoing integration of material sciences, tissue engineering, and personalized medicine will likely drive the next generation of vascular grafts.

Keywords: *Polyester Vascular Grafts, Cardiovascular Diseases, Graft Innovation, Thrombogenicity, Biocompatibility, Smart Grafts.*

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I. INTRODUCTION

Cardiovascular diseases (CVDs) have consistently remained the foremost cause of morbidity and mortality on a global scale, accounting for approximately 17.9 million deaths annually, representing 32% of all global deaths [1]. Surgical interventions aimed at restoring blood flow—such as revascularization procedures, aneurysm repairs, and trauma reconstructions—are critical components of CVD management. In such interventions, vascular grafts play an indispensable role, serving as conduits for blood flow where natural vessels are damaged or occluded.

Among synthetic vascular graft materials, polyethylene terephthalate, commonly known as polyester or Dacron, has been extensively utilized for over six decades [2]. These grafts have gained widespread clinical acceptance due to their mechanical durability, ease of handling during surgical procedures, and long-term patency in large-diameter applications [3,4]. The introduction of woven and knitted configurations has further enhanced their structural versatility, enabling adaptation to diverse clinical needs [5]. Despite their successful application, polyester grafts are not devoid of complications. Issues such as compliance mismatch, thrombogenicity, neointimal hyperplasia, and susceptibility to infection have prompted continuous innovations in graft design and surface modifications [6-8].

Recent advancements in textile engineering, polymer chemistry, and surface coating technologies have redefined the development of next-generation polyester vascular grafts. Innovations such as heparin-bonded surfaces, collagen or gelatin impregnation, and electrospun nanofiber coatings have been investigated to improve hemocompatibility, endothelialization, and resistance to microbial colonization [9-11]. Furthermore, hybrid grafts incorporating biologically active agents or drug-eluting capabilities are being explored to mitigate postoperative complications and enhance graft integration [12,13].

Given the dynamic evolution of biomaterials science and the growing demand for customized vascular solutions, a comprehensive reassessment of polyester vascular grafts is warranted. The present review aims to systematically evaluate the development, clinical applications, and material advancements associated with polyester grafts. Emphasis is placed on understanding their mechanical and biological performance, identifying limitations in current models, and exploring the potential of novel modifications and fabrication techniques to meet emerging clinical requirements. The global vascular grafts market size accounted for USD 5.98 billion in 2024 and is predicted to reach around USD 9.88 billion by 2034, growing at a CAGR of 5% from 2024 to 2034 [26] shown in Fig:01.

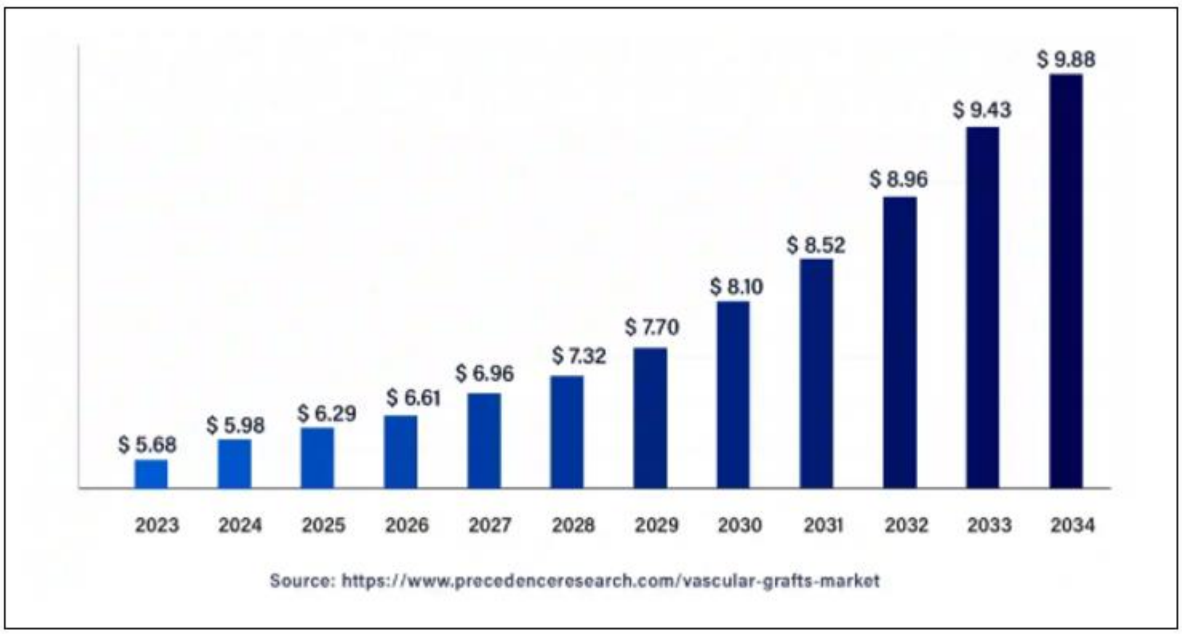

Fig: 1 Vascular Grafts Market Size and Growth 2024 to 2034

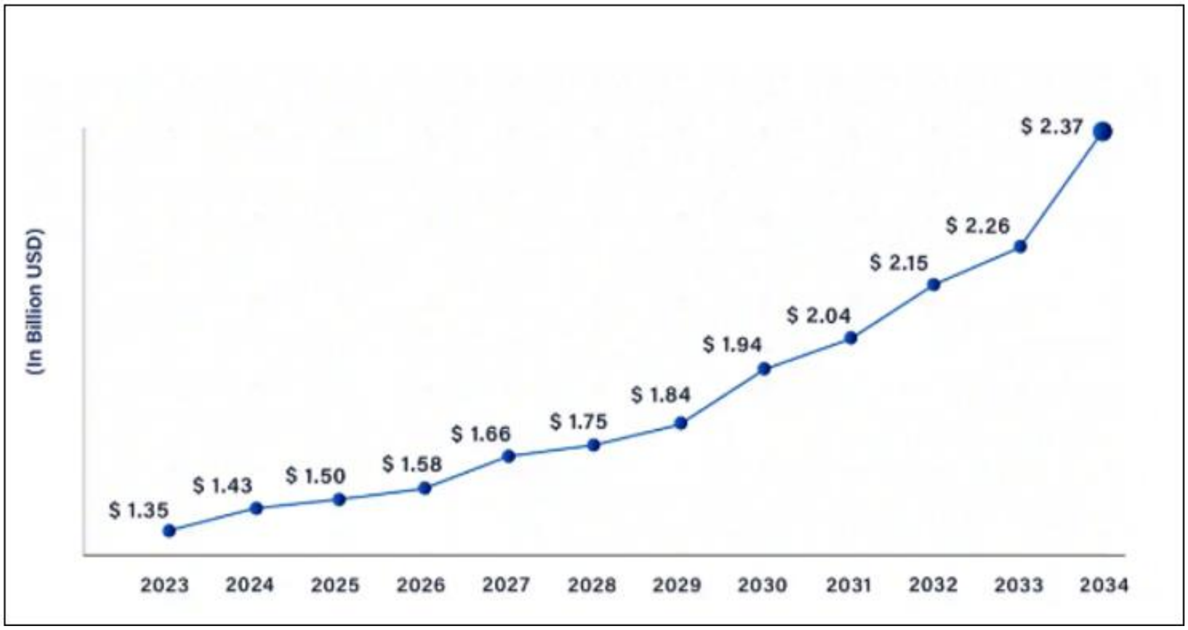

Fig: 2 Vascular Grafts Market Size and Growth 2024 to 2034

This review is particularly timely due to the increasing prevalence of complex vascular conditions, the shift towards minimally invasive and endovascular techniques, and the growing interest in biofunctional graft systems [14]. In light of these developments, a critical synthesis of existing evidence is essential to guide clinicians, researchers, and device manufacturers in optimizing graft design and therapeutic outcomes.

The current state-of-the-art indicates that while polyester grafts remain a cornerstone in vascular surgery, there exists significant room for improvement in their biocompatibility and long-term performance. Comparisons with expanded polytetrafluoroethylene (ePTFE) grafts, biological scaffolds, and tissue-engineered vessels underscore both the strengths and limitations of polyester-based systems [15,16]. As material sciences and regenerative technologies converge, polyester vascular grafts are expected to undergo further transformation, fostering the emergence of next-generation conduits that are more responsive to the physiological and anatomical complexities of patients.

II. LITERATURE REVIEW

Polyester vascular grafts, primarily composed of polyethylene terephthalate (PET), have been a cornerstone in large-diameter vascular reconstructions due to their mechanical robustness and durability. Historically, Dacron grafts demonstrated superior handling characteristics and kink resistance, but challenges such as thrombogenicity and anastomotic aneurysms persisted in early generations [27]. Contemporary designs have integrated woven or knitted configurations to optimize porosity, compliance, and surgical handling, with woven grafts offering enhanced strength and knitted grafts providing superior flexibility and tissue ingrowth potential [28,29]. Biocompatibility improvements have included collagen or gelatin sealing to reduce blood permeability and promote endothelialization [30]. Moreover, innovations such as antimicrobial coatings and heparin-bonded surfaces are being explored to minimize graft infections and thrombotic complications [31,32]. Recent advancements in electrospinning and nanofiber-based PET grafts have shown promise in replicating native extracellular matrix architecture and enhancing cellular integration, which may mark a paradigm shift toward next-generation biohybrid vascular prostheses [33,34]. Despite these advancements, long-term patency in small-diameter applications remains a significant hurdle, underscoring the need for continued material innovation and biofunctionalization strategies.

III. MECHANISM OF ACTION AND DESIGN CONSIDERATIONS

➤ *Material Properties of Polyester Vascular Grafts*

Polyester vascular grafts, specifically those made from polyethylene terephthalate (PET), are widely used in cardiovascular surgeries due to their favorable mechanical properties, such as durability, strength, and flexibility. A deeper understanding of their material properties is essential for optimizing graft performance and addressing limitations like thrombogenicity, compliance mismatch, and infection susceptibility.

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Table 1 Material Properties of Polyester Vascular Grafts

Sr. No.	Category	Details
1	Molecular Structure of Polyester	Linear polymer (PET) with ester linkages; strong and durable
2	Crystallinity	Semi-crystalline; increases strength but reduces flexibility.
3	Porosity	Knitted = high porosity (flexible); Woven = low porosity (strong).
4	Surface Energy	High surface energy promotes thrombosis; surface treatment improves biocompatibility.
5	Tensile Strength	High strength supports durability under arterial pressure.
6	Compliance	Lower than native vessels; may cause flow disturbances.
7	Thrombogenicity	Hydrophobic surface can cause platelet adhesion and clotting
8	Heparin Coating	Binds heparin to reduce thrombosis and enhance endothelial growth.
9	Electrospun Coating	Mimics ECM; supports cell attachment and reduces thrombosis.

➢ *Design Principles*

Polyester vascular grafts are meticulously engineered to replicate arterial compliance while ensuring mechanical robustness, suture retention, and ease of surgical handling. The structural configuration significantly influences graft performance; knitted polyester grafts, characterized by higher porosity, confer superior compliance and are generally preferred in settings where flexibility is prioritized. In contrast, woven polyester grafts exhibit lower porosity and higher mechanical strength, rendering them suitable for applications requiring greater resistance to pressure and external forces [2,5,22].

➢ *Performance and Efficacy*

Clinically, polyester grafts have demonstrated excellent durability, particularly in large-diameter vessel reconstructions. Patency rates exceeding 85% have been reported in procedures involving carotid and femoropopliteal arteries [1,18,25]. However, a significant concern is the occurrence of graft infections, with reported rates ranging from 2% to 5%, necessitating stringent aseptic surgical protocols and, in some cases, prophylactic antibiotic-impregnated grafts [7,21].

IV. COMPARATIVE ANALYSIS

➢ *Comparison with Existing Devices*

In comparison to expanded polytetrafluoroethylene (ePTFE) grafts, polyester grafts offer enhanced suture handling and superior structural integration within the host tissue [4,18]. Nonetheless, ePTFE grafts have been shown to maintain higher patency in small-caliber vessels (<6 mm), where polyester grafts are more prone to thrombosis and occlusion [13,24]. Biologic grafts, such as those derived from bovine pericardium, demonstrate superior remodeling potential and reduced thrombogenicity; however, they generally lack the long-term durability afforded by synthetic alternatives [14,16].

➢ *Cost and Accessibility*

From an economic and logistical standpoint, polyester grafts remain highly advantageous. Their lower manufacturing costs relative to biologically derived grafts have facilitated widespread global availability, particularly benefiting healthcare systems in resource-limited settings [6,20].

V. CHALLENGES AND LIMITATIONS

Despite their widespread use, polyester vascular grafts are subject to a range of limitations that can compromise long-term success. One major drawback is their heightened susceptibility to infection, which poses a considerable postoperative complication [7,19]. Additionally, mechanical mismatch between the graft and native vasculature may result in disturbed hemodynamics and anastomotic complications [3,5]. Polyester grafts also lack growth potential, which restricts their use in pediatric populations [6,11]. Over time, they may undergo dilation or aneurysmal degeneration, jeopardizing structural integrity [20]. Furthermore, their thrombogenicity in small-caliber vessels significantly limits their use in peripheral reconstructions [8,10,14].

VI. FUTURE PERSPECTIVES

Current advancements in vascular graft technology are aimed at mitigating existing limitations while enhancing clinical performance. Hybrid grafts that integrate synthetic scaffolds with biological components offer the potential for enhanced biocompatibility and regenerative capacity [9,11]. Drug-eluting grafts that release anti-thrombogenic agents are being investigated to reduce the incidence of early occlusion and enhance endothelialization [12,17]. Electrospun nanofiber grafts present an innovative solution with their biomimetic architecture, which promotes endothelial cell attachment and integration [23]. The development of patient-specific, 3D-printed grafts tailored to anatomical nuances has introduced the prospect of personalized vascular therapy [15]. Furthermore, smart grafts embedded with biosensors could revolutionize postoperative monitoring by enabling real-time assessment of physiological parameters and early detection of complications [16]. Ongoing research should emphasize the enhancement of graft biocompatibility, incorporation of tissue engineering strategies, and reduction of infection and thrombosis rates [6,9,14].

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VII. CONCLUSION

Polyester vascular grafts, predominantly fabricated from polyethylene terephthalate (PET), have maintained their role as a cornerstone in vascular surgery for both elective and emergency procedures. Their widespread use is attributed to favorable properties including high tensile strength, dimensional stability, resistance to biodegradation, and relatively low manufacturing costs. These characteristics make polyester grafts particularly suitable for large-diameter arterial reconstructions, such as aortic and iliofemoral bypasses. Over the decades, continuous improvements in textile engineering—such as variations in fiber orientation, porosity control, and configurations like woven and knitted patterns—have enhanced the mechanical compliance and suture retention capabilities of these grafts, thereby improving surgical handling and long-term performance.

In recent years, the scope and efficacy of polyester vascular grafts have been further expanded through interdisciplinary advancements. Innovations in surface modifications, such as heparin-bonding and antimicrobial coatings, aim to reduce thrombogenicity and infection rates—two of the most common post-implantation complications. Meanwhile, drug-eluting technologies and the incorporation of regenerative agents such as growth factors or stem cell attractants are under active investigation to promote endothelialization and facilitate integration with host vasculature. Moreover, progress in regenerative medicine and biomaterials science has catalyzed the development of hybrid grafts that combine synthetic PET scaffolds with biodegradable, bioactive layers that support cellular infiltration and remodeling.

Despite these advances, conventional polyester grafts still face significant limitations, particularly in small-diameter applications (<6 mm) where the risk of thrombosis and neointimal hyperplasia is elevated. The lack of true endothelial lining and poor compliance mismatch at the anastomotic sites also contribute to reduced long-term patency. Therefore, next-generation vascular grafts are being designed to be biofunctional and “intelligent”—capable of sensing local biochemical cues, releasing therapeutic agents in response to pathological stimuli, or even transmitting performance data via embedded microsensors. Such smart graft systems could enable personalized treatment strategies, adaptive hemodynamic performance, and earlier intervention in case of graft dysfunction.

In conclusion, while polyester vascular grafts remain indispensable in contemporary vascular surgery, ongoing research and technological innovation are pivotal to overcoming their current limitations. The future of vascular graft development will likely center on creating multifunctional, patient-tailored solutions that integrate mechanical robustness with biological compatibility, ultimately enhancing long-term graft patency and patient outcomes.

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