Design and Clinical Applications of Intracoronary Stents in Coronary Revascularization-An Updated Review

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Abstract

Background: Coronary artery disease remains a leading cause of morbidity and mortality worldwide. Percutaneous coronary intervention with stent implantation has become a primary revascularization strategy. Continuous evolution of stent technology has aimed to reduce restenosis, thrombosis, and procedural complications while improving long-term vascular outcomes. **Aim**: This review aimed to analyze the evolution, structure, indications, preparation, and procedural considerations of coronary stents, with emphasis on technological advancements and clinical implications in interventional cardiology. **Methods**: A structured narrative synthesis of coronary stent literature was conducted, focusing on historical development, device engineering, pharmacological coatings, procedural techniques, and clinical trial evidence. Key studies evaluating bare-metal stents, first-generation drug-eluting stents, second-generation platforms, and emerging technologies were reviewed. **Results**: Findings demonstrate significant improvement in clinical outcomes with drug-eluting stents compared with bare-metal stents, particularly in reducing in-stent restenosis and target vessel revascularization. Second-generation stents showed further reduction in stent thrombosis and improved biocompatibility. Newer technologies, including bioresorbable scaffolds, polymer-free stents, and ultra-thin strut designs, offer promising advancements but require further long-term validation. Procedural success is strongly influenced by lesion preparation, imaging guidance, and individualized patient selection. **Conclusion:** Coronary stent technology continues to evolve toward safer, more effective, and more biologically compatible systems. Integration of mechanical innovation and pharmacological modulation has transformed coronary intervention outcomes, although ongoing refinement is required to address complex lesions and long-term vascular responses.

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Introduction

Coronary artery disease remains one of the dominant contributors to global mortality and long-term disability. Acute coronary syndrome represents the most severe clinical expression of this disease spectrum, arising primarily from plaque disruption within coronary vessels. This pathological event initiates platelet aggregation, thrombus formation, and progressive luminal obstruction, frequently culminating in acute myocardial ischemia that demands immediate mechanical reperfusion. Percutaneous coronary intervention has progressively established itself as the standard therapeutic approach for rapid restoration of coronary perfusion in this clinical context, with continuous refinement in techniques and device technology over time. The contemporary foundation of coronary intervention was established on September 16, 1977, in Zurich, Switzerland, when Andreas Grüntzig successfully performed the first percutaneous transluminal coronary angioplasty using a DG 20-30 balloon catheter. This procedure demonstrated that mechanical dilation of stenotic coronary segments could restore blood flow and achieve sustained vessel patency in selected cases. However, balloon angioplasty as a standalone strategy was associated with considerable procedural limitations. Acute vessel closure emerged as a major complication due to elastic recoil of the arterial wall, intimal dissection, and thrombus formation at sites of plaque injury. These adverse events contributed to abrupt vessel occlusion in approximately 5% to 10% of cases, while long-term efficacy was further compromised by high rates of restenosis driven by neointimal hyperplasia.

To address these procedural limitations, bare-metal stents were introduced during the 1980s as intravascular scaffolding systems designed to maintain luminal integrity after angioplasty. The mechanical support provided by these devices effectively eliminated issues related to vessel recoil and minimized negative vascular remodeling, thereby improving immediate procedural outcomes [1][2][3]. Early devices were constructed from relatively thick stainless-steel struts, which successfully reduced acute complications associated with balloon angioplasty. Nevertheless, their clinical application revealed new challenges, particularly the risk of stent thrombosis, which necessitated the implementation of dual antiplatelet therapy to mitigate thrombotic complications. Despite improved acute outcomes, long-term follow-up studies demonstrated substantial rates of in-stent restenosis ranging from 20% to 50%, primarily attributed to smooth muscle cell proliferation and neointimal tissue formation triggered by vascular injury. The development of drug-eluting stents in the early 2000s represented a pivotal advancement in the field of interventional cardiology. These devices were engineered with a tripartite structure comprising a metallic scaffold, a polymer-based coating to regulate pharmacological release, and an antiproliferative drug designed to inhibit neointimal growth [4]. First-generation drug-eluting stents utilized stainless steel platforms with relatively thick struts and closed-cell configurations, which, while effective in drug delivery, often limited flexibility and deliverability in tortuous or heavily calcified coronary lesions. The initial pharmacological agents incorporated included paclitaxel and sirolimus. Paclitaxel exerted its effect by disrupting microtubule assembly during cell division, whereas sirolimus functioned through inhibition of the mammalian target of rapamycin pathway, thereby suppressing smooth muscle cell proliferation and reducing neointimal formation [5][6][7][8].

The introduction of drug-eluting stents resulted in a marked reduction in restenosis rates and significantly decreased the necessity for repeat revascularization procedures. Despite these benefits, early-generation devices were associated with delayed endothelial healing, which contributed to an elevated risk of late and very late stent thrombosis. Continued technological refinement has led to the development of second- and newer-generation drug-eluting stents characterized by thinner strut profiles, improved polymer biocompatibility or biodegradability, and enhanced antiproliferative drug formulations. These modifications have collectively improved vascular healing responses, reduced adverse thrombotic events, and expanded the applicability of stent-based interventions in complex coronary pathologies such as diabetes-associated diffuse disease, heavily calcified lesions, and bifurcation involvement. In contemporary practice, intracoronary stenting remains a fundamental component of coronary artery disease management, with ongoing innovation continuously optimizing device performance, safety profiles, and long-term clinical outcomes.

Anatomy and Physiology

Coronary stents represent engineered intravascular devices designed as expandable tubular mesh frameworks intended to preserve luminal integrity following percutaneous coronary intervention. Their structural configuration is based on three interdependent anatomical components that collectively determine mechanical performance, pharmacological function, and biological interaction with the vascular wall. The primary structural element is the metallic platform, which provides radial strength necessary to counteract elastic recoil of the coronary artery while maintaining sufficient flexibility to traverse tortuous and calcified coronary segments. Early designs relied predominantly on stainless steel, which provided adequate support but limited conformability in complex lesions. Subsequent technological refinements introduced cobalt-chromium and platinum-chromium alloys, which allowed the development of thinner strut profiles while preserving radial force. This reduction in strut thickness improves vessel conformability, enhances deliverability through narrowed or angulated anatomy, and reduces vessel wall injury, which in turn lowers

inflammatory response and promotes improved vascular healing. The second structural component is the polymer coating, which is primarily utilized in drug-eluting stents to control the kinetics of antiproliferative drug release. This coating functions as a pharmacological reservoir that modulates drug diffusion over a defined period, ensuring sustained local therapeutic concentrations while minimizing systemic exposure. Polymer characteristics vary across devices and may include hydrophobic, hydrophilic, or bioabsorbable formulations, each designed to optimize biocompatibility and reduce chronic inflammatory responses. Bioabsorbable polymers, in particular, have been developed to eliminate long-term polymer persistence within the vessel wall, thereby reducing late inflammatory reactions and potentially lowering the risk of very late stent thrombosis. The interaction between the polymer surface and circulating blood elements plays a central role in determining endothelial healing dynamics and overall device safety [8][9].

The third component is the antiproliferative drug, which is incorporated to inhibit vascular smooth muscle cell proliferation and thereby reduce neointimal hyperplasia, the principal mechanism underlying in-stent restenosis. Early pharmacological strategies relied primarily on agents such as sirolimus and paclitaxel. Sirolimus functions through inhibition of the mammalian target of rapamycin pathway, leading to cell cycle arrest and suppression of smooth muscle cell proliferation. Paclitaxel acts by stabilizing microtubules and preventing mitotic progression. Comparative evidence suggests that sirolimus and its analogs demonstrate superior efficacy in reducing neointimal proliferation and restenosis rates compared with paclitaxel, although both drug classes exhibit comparable risks regarding thrombotic events and myocardial infarction in certain clinical contexts [9]. Modern stent platforms predominantly utilize sirolimus derivatives, including everolimus, zotarolimus, biolimus, and novolimus, which offer improved pharmacokinetic profiles, enhanced tissue compatibility, and reduced adverse vascular responses [10]. From a physiological perspective, coronary stents function as mechanical scaffolds that maintain vessel patency by counteracting acute recoil, sealing dissections created during balloon angioplasty, and preventing maladaptive vascular remodeling. Their deployment restores coronary blood flow, thereby alleviating myocardial ischemia and improving oxygen delivery to cardiac tissue. However, stent implantation also initiates a complex vascular healing cascade characterized by endothelial injury, platelet activation, and inflammatory cell recruitment. The restoration of endothelial integrity over stent struts, referred to as reendothelialization, is a critical determinant of long-term device safety, as incomplete endothelial coverage is strongly associated with thrombogenic risk. Drug-eluting stents are specifically designed to regulate this balance by suppressing excessive smooth muscle proliferation while permitting controlled endothelial recovery, thereby reducing restenosis without fully inhibiting physiological healing processes [10].

Anatomical variability of coronary vessels and lesion-specific characteristics significantly influence procedural planning, stent selection, and long-term outcomes. Accurate stent sizing is essential and is typically based on the maximal diameter of the distal reference vessel segment to avoid complications associated with underexpansion or oversizing. Inadequate sizing may result in stent malapposition, edge dissections, or vessel trauma, each of which is associated with increased risk of restenosis or thrombosis. In complex lesions, particularly those involving heavy calcification, intracoronary imaging modalities such as intravascular ultrasound or optical coherence tomography are frequently employed to provide high-resolution assessment of plaque morphology, vessel diameter, and lesion length. These imaging techniques facilitate optimization of lesion preparation strategies, including the potential use of adjunctive plaque modification techniques such as rotational, orbital, or laser atherectomy to improve stent expansion and apposition. Special anatomical challenges arise in bifurcation lesions, where stent deployment may compromise side-branch perfusion due to plaque shift or carinal displacement. In such cases, dedicated bifurcation techniques, including provisional stenting or dual-stent strategies, may be required to maintain adequate flow in both main and side branches. Overall, the integration of structural engineering, pharmacological modulation, and individualized anatomical assessment underscores the physiological role of coronary stents in contemporary interventional cardiology. These devices continue to evolve toward improved safety, enhanced deliverability, and optimized vascular healing responses, contributing to sustained improvements in clinical outcomes for patients with coronary artery disease [10].

Indications

Coronary stents are integral to contemporary management strategies for coronary artery disease, particularly in the context of acute coronary syndromes, which include ST-elevation myocardial infarction, non-ST-elevation myocardial infarction, and unstable angina. In these high-risk clinical scenarios, primary percutaneous coronary intervention with stent deployment is established as the preferred reperfusion strategy. This approach facilitates rapid restoration of coronary blood flow, reduces myocardial ischemic burden, limits infarct size, and improves short- and long-term survival outcomes. The urgency of intervention in acute coronary syndromes is driven by the need to prevent ongoing myocardial necrosis and to stabilize the culprit lesion responsible for acute vessel occlusion. Beyond acute settings, coronary stent implantation is also indicated in patients with stable ischemic heart disease when symptoms persist despite optimized pharmacological therapy or when objective testing demonstrates significant myocardial ischemia. In such cases, revascularization is pursued to improve functional capacity, alleviate anginal symptoms, and enhance quality of life. Stents are frequently deployed following successful balloon angioplasty of hemodynamically

significant lesions, as angioplasty alone is associated with procedural limitations including endothelial disruption and plaque dissection. These vascular injuries increase the likelihood of acute thrombotic occlusion and contribute to long-term restenosis. Without stent support, restenosis rates after balloon angioplasty alone may approach 50 percent, whereas both bare-metal and drug-eluting stents substantially reduce restenosis, target vessel failure, and the need for repeat revascularization procedures [11].

Coronary stent implantation is indicated across multiple clinical presentations, including ST-elevation myocardial infarction or non-ST-elevation acute coronary syndromes requiring urgent mechanical reperfusion. It is also indicated in stable angina that remains refractory to guideline-directed medical therapy despite optimal pharmacological management. Additional indications include patients presenting with anginal equivalents such as unexplained dyspnea, arrhythmias, dizziness, or syncope, particularly when these symptoms are linked to myocardial ischemia. Furthermore, stent placement is justified in patients demonstrating objective evidence of moderate to extensive myocardial ischemia on noninvasive diagnostic testing, including stress imaging modalities [12][13][14][15]. The role of bare-metal stents has significantly diminished following the introduction of drug-eluting stents, which offer superior outcomes in terms of restenosis prevention and long-term vessel patency. However, bare-metal stents may still be considered in select clinical circumstances. These include patients requiring early noncardiac surgery within four to six weeks following percutaneous coronary intervention, individuals at high risk of bleeding who may not tolerate prolonged dual antiplatelet therapy, and patients with anticipated poor adherence to extended antiplatelet regimens. Despite these limited indications, evidence consistently demonstrates superior outcomes with contemporary drug-eluting stents compared with both early-generation drug-eluting platforms and bare-metal stents [16][17]. As a result, current-generation drug-eluting stents are preferred in most clinical scenarios due to their improved safety profiles, reduced restenosis rates, and enhanced biocompatibility. Technological advancements have also expanded the range of stent options and procedural strategies available to interventional cardiologists. Self-expanding stents have been developed to accommodate dynamic vessel geometry, particularly in acute myocardial infarction where vessel diameter may be altered by thrombus burden or vasomotor tone. In addition, bioresorbable scaffolds are under ongoing investigation as a means of reducing long-term foreign body presence within the coronary vasculature, thereby potentially decreasing late adverse events. Complex coronary lesions, especially bifurcation disease, require specialized stenting techniques to optimize outcomes and minimize complications. Techniques such as the double-kissing crush strategy have demonstrated improved results in reducing restenosis and stent-related adverse events in selected anatomical settings. In selected patients, percutaneous coronary intervention with stent placement is preferred over coronary artery bypass grafting, particularly in cases involving single-vessel or limited two-vessel disease affecting the right coronary or circumflex arteries. However, the decision between percutaneous and surgical revascularization is highly individualized, taking into account coronary anatomy, lesion complexity, comorbid conditions such as diabetes mellitus, surgical risk, and patient preferences. Within this decision-making framework, coronary stents remain a central therapeutic tool, providing effective, minimally invasive revascularization across a broad spectrum of coronary artery disease presentations.

Contraindications

Coronary stenting is a cornerstone intervention in coronary artery disease management; however, its application requires careful patient selection due to several absolute and relative contraindications that may compromise safety or therapeutic efficacy. The most critical absolute contraindication is the inability to tolerate dual antiplatelet therapy. Since stent implantation, particularly with drug-eluting stents, depends on prolonged platelet inhibition to prevent stent thrombosis, patients who cannot safely receive aspirin or P2Y12 inhibitors due to hypersensitivity, high bleeding risk, or nonadherence are unsuitable candidates. Clinical scenarios such as active gastrointestinal hemorrhage, recent intracranial bleeding, or inherited bleeding disorders significantly increase procedural risk and preclude safe antiplatelet administration. Hematological instability represents another major contraindication, particularly severe anemia or thrombocytopenia. Reduced hemoglobin levels or platelet counts impair hemostasis and substantially elevate the risk of peri-procedural and post-procedural bleeding complications. Anatomical limitations also serve as absolute contraindications, particularly in cases of diffuse, small-vessel, or heavily calcified coronary disease that cannot accommodate safe stent deployment. In such circumstances, technical failure or suboptimal expansion may lead to poor outcomes. Additionally, patients with limited life expectancy due to advanced malignancy, end-stage organ failure, or severe systemic illness are generally excluded because the procedural benefits do not outweigh the risks [12].

Relative contraindications include active systemic infection or sepsis, where implantation of a foreign intravascular device increases the risk of infectious complications, including endovascular infection. Severe renal impairment, whether chronic or acute, also poses significant risk due to contrast-induced nephropathy, often necessitating alternative strategies or contrast minimization protocols. Planned noncardiac surgery requiring early discontinuation of antiplatelet therapy within four to six weeks after percutaneous coronary intervention presents another challenge, as interruption of dual antiplatelet therapy increases the risk of stent thrombosis; in such cases, alternative revascularization strategies or bare-metal stent consideration may be more appropriate. Additional relative contraindications include significant coagulopathies or bleeding diatheses that predispose to uncontrolled hemorrhage

during or after intervention. Pregnancy is also considered a relative contraindication due to concerns related to ionizing radiation exposure, contrast agent effects, and mandatory antiplatelet therapy requirements, reserving intervention only for life-threatening indications. Further procedural considerations involve coronary anatomy that is not suitable for percutaneous intervention, such as chronic total occlusions, severe tortuosity, or ostial lesions, where surgical revascularization may offer superior outcomes. Hypersensitivity reactions to contrast media, metallic stent components such as nickel, polymer coatings, or antiproliferative drugs may also restrict stent use unless appropriate premedication or alternative devices are available. Finally, acute aortic dissection must be excluded in patients presenting with chest pain, as misdiagnosis and inappropriate stent placement in such cases can lead to catastrophic outcomes.

Equipment

Percutaneous coronary intervention with stent implantation represents a highly specialized interventional procedure that relies on a sophisticated array of technological systems and dedicated devices to ensure procedural precision, safety, and therapeutic success. The intervention is conducted within a cardiac catheterization laboratory, which is designed as a controlled imaging and procedural environment equipped with advanced single-plane or biplane cineangiographic systems that provide real-time fluoroscopic visualization of coronary anatomy. These imaging systems are complemented by adjunctive intracoronary diagnostic technologies such as intravascular ultrasound and optical coherence tomography, which offer high-resolution cross-sectional imaging of vessel morphology, plaque composition, and stent apposition. The procedural environment also incorporates motorized radiolucent tables that facilitate optimal patient positioning while allowing unobstructed imaging acquisition, in addition to integrated hemodynamic monitoring systems that continuously assess blood pressure, electrocardiographic activity, and oxygenation parameters throughout the intervention to maintain patient stability. Vascular access constitutes the initial step in the procedure and is typically achieved through either the radial or femoral arterial approach. The selection of access site is influenced by operator expertise, patient anatomy, bleeding risk, and anticipated procedural complexity. Once arterial access is established, a guiding catheter, generally sized at 6 French or larger, is advanced to engage the coronary ostium. This catheter plays a critical role in providing adequate back-up support for device delivery, enabling precise coaxial alignment with the coronary artery, and allowing controlled contrast injection for angiographic visualization. Optimal catheter selection is essential to ensure stability during device manipulation and to facilitate successful navigation of complex coronary anatomy. Systemic anticoagulation is a fundamental component of procedural management aimed at minimizing the risk of thrombus formation during coronary instrumentation. Anticoagulant agents such as unfractionated heparin, enoxaparin, or bivalirudin are administered to maintain an activated clotting time exceeding 250 seconds throughout the procedure. This therapeutic anticoagulation reduces the likelihood of catheter-associated thrombosis and ensures patency of the coronary circulation during device manipulation [16][17].

Fig. 1: Coronary Stents.

Following coronary engagement, a 0.014-inch guidewire is carefully advanced across the target lesion under fluoroscopic guidance. This guidewire functions as a mechanical rail system over which balloons and stents are delivered to the site of stenosis. Various guidewire types are employed depending on lesion complexity and vessel

tortuosity. Standard workhorse wires are used for routine interventions, while hydrophilic-coated wires facilitate navigation through tortuous or highly stenotic vessels due to their enhanced lubricity. In contrast, extra-support guidewires provide increased stiffness and backup support in complex or heavily calcified lesions where device delivery may otherwise be challenging. Once the guidewire successfully traverses the lesion, balloon delivery systems and stent platforms are advanced over the wire to the target segment. The stent, pre-mounted on a balloon catheter, is precisely positioned across the lesion and deployed through controlled balloon inflation using a high-pressure inflation device known as an insufflator. This inflation process expands the stent radially, embedding it into the arterial wall and restoring luminal patency by compressing atherosclerotic plaque and stabilizing the vessel structure. Balloon inflation pressures are carefully titrated to achieve optimal stent expansion while minimizing the risk of vessel rupture or dissection. Stent technology has undergone significant evolution to address complications such as restenosis, thrombosis, and delayed endothelial healing. Several categories of stents have received regulatory approval and are currently utilized in clinical practice. Bare-metal stents, typically constructed from stainless steel, provide structural scaffolding but are associated with higher rates of restenosis due to neointimal hyperplasia. Durable polymer drug-eluting stents, commonly composed of cobalt-chromium or platinum-chromium platforms, incorporate antiproliferative agents such as everolimus or zotarolimus, which are released locally to inhibit smooth muscle cell proliferation and reduce neointimal formation. Bioabsorbable polymer drug-eluting stents represent an advancement in which the polymer coating gradually degrades, thereby reducing long-term polymer exposure while maintaining drug delivery capacity during the critical healing phase. Polymer-free drug-coated stents utilize microstructured metallic surfaces to retain and release drugs such as biolimus, offering the potential advantage of shortened dual antiplatelet therapy duration. Bioresorbable vascular scaffolds are designed to provide temporary mechanical support before complete resorption, eliminating permanent metallic implants from the coronary circulation. Drug-eluting balloons provide an alternative strategy in which antiproliferative drugs are delivered directly to the vessel wall without leaving behind a permanent scaffold, making them particularly useful in select lesion subsets [18].

Drug-eluting stents are structurally composed of three essential elements, including a metallic scaffold, an active pharmacological agent, and a carrier system that regulates drug release. The metallic component, typically stainless steel or cobalt-chromium alloy, provides long-term radial strength to counteract elastic recoil of the coronary artery. The pharmacological agents used within these systems exert their therapeutic effect by inhibiting intracellular signaling pathways responsible for smooth muscle cell proliferation and neointimal hyperplasia. Rapamycin derivatives bind to the intracellular protein FKBP-12, forming a complex that inhibits the mammalian target of rapamycin pathway. This inhibition leads to upregulation of p27, resulting in cell cycle arrest at the G1 to S phase transition and suppression of DNA synthesis. Taxane-based agents, in contrast, interfere with microtubule dynamics essential for mitotic progression, thereby arresting cells in the G2 phase and preventing proliferation. The polymer coating serves as a drug reservoir and release regulator, ensuring sustained and controlled pharmacological delivery to the vessel wall. These polymers are typically composed of biodegradable materials such as poly-L-lactide and poly-D,L-lactic-co-glycolic acid, which degrade into lactic acid and glycolic acid and are subsequently metabolized into carbon dioxide and water. First-generation drug-eluting stents utilized sirolimus or paclitaxel coatings on stainless steel platforms, whereas second-generation devices employ everolimus or zotarolimus on more advanced cobalt-chromium or platinum-chromium frameworks. Drug release is governed by diffusion through microporous polymer structures, enabling controlled elution over time. In addition to conventional stents, specialized devices have been developed to address specific anatomical and clinical scenarios. Drug-coated balloons, which lack a permanent metallic scaffold, provide localized drug delivery without long-term implantation. Bioresorbable scaffolds similarly dissolve after fulfilling their mechanical role. Dedicated bifurcation stents and covered stents are designed for complex lesion subsets, including coronary bifurcations and vessel perforations respectively, thereby expanding the therapeutic armamentarium available to interventional cardiologists [19][20].

A fundamental limitation of bare-metal stents is the development of in-stent restenosis, primarily driven by neointimal hyperplasia resulting from vascular injury induced during implantation. This process involves smooth muscle cell migration and proliferation within the intimal layer, leading to progressive luminal narrowing. Drug-eluting stents were developed to counteract this mechanism by delivering antiproliferative agents locally at the site of injury, thereby inhibiting smooth muscle cell activity while minimizing systemic toxicity. The pharmacodynamic efficacy of these agents is influenced by multiple factors, including diffusion kinetics, tissue retention, distribution patterns, and local vascular toxicity. Achieving an optimal balance between effective drug delivery and minimization of adverse local effects is essential for long-term procedural success. Drug diffusion is further modulated by coating thickness, drug loading concentration, polymer-to-drug ratio, and the physicochemical properties of the agent, particularly its partition coefficient, which directly influences diffusion dynamics. Drug release from stent platforms occurs in a biphasic manner. An initial rapid release phase is observed due to immediate dissolution of surface-bound drug, following first-order kinetic principles and resulting in a substantial proportion of drug release within the first few days post-implantation. This is followed by a sustained release phase characterized by slower diffusion through the polymer matrix, allowing prolonged therapeutic exposure. Higher drug loading concentrations are associated with an accentuated early release phase, which may influence both efficacy and local tissue response. The distribution of pharmacological agents within arterial tissue is significantly influenced by their lipophilic or hydrophilic properties.

Hydrophilic compounds tend to disperse more readily within the aqueous vascular environment, resulting in broader distribution but lower local tissue retention. In contrast, hydrophobic agents demonstrate greater tissue affinity, leading to higher localized concentrations and prolonged retention within the arterial wall. Lipophilic drugs exhibit intermediate characteristics with slower and more sustained release profiles [21]. Experimental and clinical evidence has demonstrated that agents such as rapamycin and paclitaxel may upregulate prothrombotic mediators, including tissue factor and plasminogen activator inhibitor-1. When local vascular toxicity occurs, delayed endothelial healing may ensue, prolonging the thrombogenic window at the stent site. Additionally, degradation products of biodegradable polymers, such as lactic acid and glycolic acid, may contribute to local acidification, further enhancing platelet activation. These processes collectively increase the risk of stent thrombosis, particularly in situations where antithrombotic therapy is interrupted prematurely. Furthermore, hypersensitivity reactions to polymer coatings have been implicated in chronic inflammatory responses, which may further compromise endothelial healing and long-term vascular outcomes [22][23][2].

Evolution of Stent Technology

The evolution of coronary stent technology reflects a continuous effort to overcome the limitations of earlier percutaneous coronary intervention strategies and to improve long-term vascular outcomes in patients with coronary artery disease. This progression has moved through multiple generations of drug-eluting and specialized stents, each designed to refine mechanical performance, enhance biological compatibility, and reduce adverse cardiovascular events such as restenosis, thrombosis, and target vessel failure. The development of these devices has been closely guided by clinical trials, long-term outcome studies, and advances in material science and pharmacology. First-generation drug-eluting stents represented a major advancement over bare-metal stents, particularly in reducing restenosis rates and the need for repeat revascularization. The TAXUS study provided pivotal evidence demonstrating that first-generation drug-eluting stents significantly reduced target vessel revascularization by approximately 50 percent over a five-year follow-up period compared with bare-metal stents [24][25]. This improvement was primarily attributed to the ability of the stent to locally deliver antiproliferative agents that inhibit smooth muscle cell proliferation and neointimal hyperplasia, the principal mechanisms responsible for restenosis. Despite these benefits, long-term follow-up revealed important safety concerns, most notably the occurrence of very late stent thrombosis. An increase in myocardial infarction rates observed over extended follow-up periods in the TAXUS trial population was linked to late thrombotic events occurring after the initial healing phase.

Mechanistic investigations suggested that the increased risk of late thrombosis was associated with incomplete endothelialization of the stent surface and adverse biological responses to the polymer-drug matrix used in early devices. In some cases, up to 60 percent of the stent surface was found to remain unendothelialized even after prolonged implantation periods. This persistent lack of endothelial coverage created a thrombogenic environment, increasing the likelihood of platelet activation and thrombus formation. The durable polymers used in first-generation stents were also implicated in provoking chronic inflammatory responses, further impairing vascular healing and contributing to delayed endothelial recovery. While these stents were highly effective in suppressing neointimal proliferation, their inability to promote complete and timely endothelialization ultimately limited their long-term safety profile. In response to these limitations, second-generation drug-eluting stents were developed with significant improvements in both structural design and pharmacological delivery systems. One of the most important modifications was the transition from stainless steel platforms to cobalt-chromium alloys, which allowed the production of thinner struts while maintaining adequate radial strength. The reduction in strut thickness contributed to decreased vessel injury during deployment, improved flexibility, and enhanced deliverability in complex coronary anatomy. Thinner struts also facilitated more rapid endothelialization and reduced local inflammatory responses, thereby improving overall vascular healing. Second-generation stents also incorporated more biocompatible polymer coatings, including fluorinated polymers that demonstrated improved thromboresistance and reduced inflammatory potential. These advances contributed to a marked reduction in late thrombotic complications compared with first-generation devices. The primary antiproliferative agents used in these newer stents included everolimus and zotarolimus, both of which are sirolimus analogs with improved pharmacokinetic profiles and enhanced safety characteristics. Large-scale clinical trials, including the SPIRIT II, III, and IV studies as well as the COMPARE trial, demonstrated that everolimus-eluting stents significantly reduced major adverse cardiovascular events by approximately 30 to 40 percent over 24 months compared with paclitaxel-eluting stents [26][27]. Furthermore, these second-generation devices were associated with a substantial reduction in very late stent thrombosis, estimated at approximately 70 percent, representing a major milestone in improving long-term safety outcomes in interventional cardiology.

The continued evolution of stent technology has led to the development of third-generation drug-eluting stents, which focus on further improving biocompatibility, reducing polymer burden, and enhancing long-term vascular healing. These stents often feature ultra-thin strut designs and may incorporate bioabsorbable polymers, polymer-free drug delivery systems, or fully resorbable scaffolds. Clinical evidence suggests that reductions in strut thickness are strongly associated with improved clinical outcomes, including lower rates of target lesion failure and stent thrombosis. In the BIOFLOW V trial, a third-generation stent with a 60-micron strut thickness demonstrated significantly better

outcomes compared with a thicker 82-micron stent with a durable fluoropolymer coating, with improvements attributed largely to the enhanced hemodynamic and healing properties of thinner struts. Meta-analytical data further support these findings. A study by Bangalore and Stone comparing ultra-thin stents with strut thickness below 70 microns to thicker second-generation stents demonstrated a trend toward superior clinical outcomes in the ultra-thin group, particularly in terms of reduced target lesion failure and stent thrombosis [28][29]. Similarly, a meta-analysis conducted by Palmerini evaluating bioabsorbable polymer-based drug-eluting stents showed a modest reduction in cardiac death and myocardial infarction compared with bare-metal stents, along with lower rates of target vessel revascularization. However, when compared with contemporary durable-polymer drug-eluting stents, no significant superiority was observed, indicating that incremental improvements rather than transformative differences characterize this generation of devices. The EVOLVE II trial further supported this observation, demonstrating no statistically significant difference in target lesion failure at 36 months between bioabsorbable polymer stents and durable polymer drug-eluting stents [30][31].

Another significant innovation within third-generation stent development is the emergence of polymer-free drug-coated stents. These devices typically consist of stainless steel platforms with microstructured surfaces that allow direct adsorption of antiproliferative drugs, eliminating the need for a polymer carrier. This design aims to reduce inflammation associated with polymer degradation and enable shorter durations of dual antiplatelet therapy, which is particularly advantageous in patients with high bleeding risk. One example involves the use of biolimus, a highly lipophilic drug that exhibits approximately tenfold greater lipophilicity compared with sirolimus, everolimus, and zotarolimus. This property facilitates prolonged retention within vascular tissue and enables sustained drug release through passive diffusion from the vessel wall. The LEADERS FREE trial demonstrated that drug-coated stents significantly reduced target lesion failure compared with bare-metal stents, while also lowering rates of myocardial infarction and cardiac death [32][33]. However, stent thrombosis rates remained comparable between the two groups, a finding attributed in part to the relatively large strut thickness of approximately 120 microns in the device studied. This observation has driven ongoing efforts to develop newer iterations with thinner and more flexible struts to improve safety outcomes further.

Future directions in stent technology include the development of thin-strut drug-filled stents, which represent a novel structural concept. These devices typically incorporate a multilayer metallic design consisting of an outer cobalt alloy layer, an intermediate tantalum layer, and a central lumen that is filled with antiproliferative medication. This design enables controlled drug release directly from within the stent structure while maintaining mechanical integrity. The RevElution trial evaluated this approach and demonstrated reduced late luminal loss at nine months, suggesting improved inhibition of neointimal proliferation and favorable vascular healing responses [34][35][36][37]. In addition to these evolving drug-eluting platforms, specialized stent systems continue to play a crucial role in managing complex coronary anatomy. Bifurcation stents are designed to optimize outcomes in lesions involving vessel branching points, where conventional stenting techniques may compromise side branch flow or lead to suboptimal expansion. Covered stents are used in the management of coronary artery perforations and other high-risk procedural complications, providing immediate sealing of vessel defects and preventing life-threatening hemorrhage [19][20]. These specialized devices underscore the expanding versatility of stent technology in addressing increasingly complex interventional challenges. Overall, the evolution of coronary stent technology reflects a progressive refinement of mechanical design, pharmacological strategy, and biological compatibility. Each generation has addressed specific limitations of its predecessors, resulting in significant improvements in clinical outcomes and procedural safety [37].

Preparation

Preparation for coronary stent implantation within the context of percutaneous coronary intervention requires a structured and systematic pre-procedural approach aimed at optimizing patient safety, minimizing procedural complications, and ensuring optimal clinical outcomes. The process begins with a comprehensive clinical assessment that includes a detailed evaluation of the patient's cardiovascular history, current disease burden, and associated comorbid conditions. Particular attention is directed toward prior ischemic events, established coronary artery disease, heart failure status, arrhythmia history, and any documented bleeding tendencies. This initial evaluation is essential for risk stratification and for guiding both procedural planning and post-procedural management. In addition, a careful assessment of potential hypersensitivity reactions, particularly to iodinated contrast media or previously implanted cardiovascular devices, is necessary to prevent intra-procedural complications. Patients scheduled for elective coronary intervention are typically instructed to observe a fasting period of approximately six to eight hours prior to the procedure. This requirement is particularly important in cases where procedural sedation is anticipated, as it reduces the risk of aspiration and associated pulmonary complications. Pharmacological preparation is equally critical, with dual antiplatelet therapy representing a cornerstone of pre-procedural management. Aspirin in combination with a P2Y12 receptor inhibitor such as clopidogrel is initiated or confirmed prior to intervention, and loading doses are administered when clinically indicated to ensure adequate platelet inhibition at the time of stent deployment. This antiplatelet strategy is fundamental to reducing the risk of acute and subacute stent thrombosis. Baseline laboratory investigations are performed to establish physiological parameters and identify potential risk factors for complications. These typically include a complete blood count to assess hemoglobin levels and platelet counts, renal function tests

and metabolic panels to evaluate electrolyte balance and kidney performance, coagulation profiles to assess bleeding risk, and blood typing with crossmatching in case transfusion is required. A baseline electrocardiogram is also obtained to document cardiac rhythm and detect ischemic changes, while prior imaging studies such as echocardiography or coronary computed tomography angiography are reviewed to assist in anatomical and functional planning of the procedure. On the day of intervention, continuation of most cardiovascular medications is generally recommended to maintain hemodynamic stability. However, certain agents, particularly those with nephrotoxic potential or those affecting renal perfusion, may be temporarily withheld. Similarly, medications such as metformin are often suspended in patients at risk of contrast-induced nephropathy due to the potential for lactic acidosis in the setting of renal dysfunction. Intravenous hydration is frequently administered, especially in individuals with pre-existing chronic kidney disease, as adequate volume expansion has been shown to reduce the incidence of contrast-associated renal injury [38].

Informed consent constitutes a critical component of procedural preparation. During this process, patients are provided with a detailed explanation of the procedure, including its purpose, technical steps, and expected benefits. The discussion also includes a comprehensive review of potential risks such as bleeding, vascular access complications, arrhythmias, stroke, myocardial infarction, and the rare but serious possibility of requiring emergency coronary artery bypass surgery. The necessity for prolonged continuation of dual antiplatelet therapy following stent implantation is also emphasized, as adherence to this regimen is essential for preventing thrombotic complications. Selection of vascular access, typically radial or femoral, is determined based on patient-specific anatomical considerations, bleeding risk, and operator expertise, with radial access increasingly preferred due to its lower incidence of access-site bleeding and improved patient comfort. Intra-procedural preparation of the coronary vessel is a critical determinant of procedural success. Initial balloon angioplasty is commonly performed to evaluate lesion compliance, determine the degree of stenosis, and provide preliminary expansion of the affected segment. This step also facilitates accurate measurement of lesion length and assists in selecting appropriate stent dimensions. In certain cases, balloon dilation alone may reveal inadequate lesion expansion, suggesting the presence of significant calcification or fibrotic plaque burden. Such lesions present technical challenges for stent delivery and expansion, necessitating additional lesion modification techniques. In these situations, adjunctive procedures such as rotational atherectomy or orbital atherectomy may be employed to debulk and modify calcified plaque, thereby improving vessel compliance and enabling successful stent placement [37][38].

Throughout the intervention, careful attention is given to minimizing contrast volume and radiation exposure, particularly in patients with impaired renal function or other risk factors for contrast-induced nephropathy. Procedural sedation is typically maintained at a light to moderate level, ensuring patient comfort while preserving spontaneous respiration and responsiveness, which allows continuous neurological and hemodynamic assessment. Continuous monitoring of vital parameters is maintained throughout the procedure to detect early signs of hemodynamic instability or ischemic complications. Following completion of stent implantation, patients require close post-procedural observation to identify early complications such as bleeding at the access site, hematoma formation, arrhythmias, or recurrent ischemic symptoms. Renal function is closely monitored in the immediate post-procedural period due to the potential nephrotoxic effects of contrast media. Long-term management includes structured patient education focusing on strict adherence to dual antiplatelet therapy, modification of cardiovascular risk factors, dietary and lifestyle adjustments, and adherence to scheduled follow-up evaluations. This comprehensive preparatory and post-procedural framework is essential for optimizing outcomes and reducing the incidence of adverse cardiovascular events following coronary stent implantation [39].

Conclusion

Coronary stent technology remains central to contemporary management of coronary artery disease. Continuous refinement in stent design, pharmacology, and procedural technique has significantly improved outcomes across acute and chronic coronary syndromes. Drug-eluting platforms reduced restenosis and repeat revascularization compared with bare-metal stents, while newer generations improved endothelial healing and reduced stent thrombosis. Procedural success now depends on integrated assessment of anatomy, lesion complexity, and patient-specific risk factors, supported by advanced imaging and adjunctive plaque modification strategies. Despite major progress, challenges persist, including late thrombotic risk, polymer-related inflammation, and limitations in complex calcified or bifurcation lesions. Future directions focus on bioresorbable materials, polymer-free drug delivery, and ultra-thin strut designs to optimize vascular healing. Long-term outcomes continue to improve through better antiplatelet strategies and individualized interventional planning. Coronary stents therefore represent an evolving therapeutic platform that combines mechanical support with targeted pharmacological intervention to restore perfusion and improve survival in coronary artery disease.

References

1. Aloia E, Orselli P, Sciaccaluga C. Triple Antithrombotic Therapy vs. Double Antithrombotic Therapy: One Scenario, 8 Questions, Many Conclusions. Curr Cardiol Rev. 2019;15(3):219-223.

2. Kar S. Outcomes of New-Generation Drug-Eluting Stents in Women with Acute Myocardial Infarction. Curr Cardiol Rep. 2019 Jan 10;21(1):2.
3. Douketis JD, Darvish-Kazem S, Spencer N, Tafur A. Perioperative management of patients who are receiving antiplatelet therapy: a case-based, evidence-informed approach. Pol Arch Intern Med. 2018 Dec 21;128(12):771-778.
4. Htay T, Liu MW. Drug-eluting stent: a review and update. Vasc Health Risk Manag. 2005;1(4):263-76.
5. Stefanini GG, Byrne RA, Windecker S, Kastrati A. State of the art: coronary artery stents - past, present and future. EuroIntervention. 2017 Aug 25;13(6):706-716.
6. Barton M, Grüntzig J, Husmann M, Rösch J. Balloon Angioplasty - The Legacy of Andreas Grüntzig, M.D. (1939-1985). Front Cardiovasc Med. 2014;1:15.
7. Kostić J, Beleslin B, Nedeljković M, Ostojić M. [Pioneers of invasive cardiovascular medicine--Charles Theodore Dotter and colleagues: short historical review]. Srp Arh Celok Lek. 2014 Jan-Feb;142(1-2):131-7.
8. Tan C, Schatz RA. The History of Coronary Stenting. Interv Cardiol Clin. 2016 Jul;5(3):271-280.
9. Kastrati A, Dibra A, Eberle S, Mehilli J, Suárez de Lezo J, Goy JJ, Ulm K, Schömig A. Sirolimus-eluting stents vs paclitaxel-eluting stents in patients with coronary artery disease: meta-analysis of randomized trials. JAMA. 2005 Aug 17;294(7):819-25.
10. Lee DH, de la Torre Hernandez JM. The Newest Generation of Drug-eluting Stents and Beyond. Eur Cardiol. 2018 Aug;13(1):54-59.
11. Collet C, Grundeken MJ, Asano T, Onuma Y, Wijns W, Serruys PW. State of the art: coronary angiography. EuroIntervention. 2017 Aug 25;13(6):634-643.
12. Zimmermann FM, Omerovic E, Fournier S, Kelbæk H, Johnson NP, Rothenbühler M, Xaplanteris P, Abdel-Wahab M, Barbato E, Høfsten DE, Tonino PAL, Boxma-de Klerk BM, Fearon WF, Køber L, Smits PC, De Bruyne B, Pijls NHJ, Jüni P, Engstrøm T. Fractional flow reserve-guided percutaneous coronary intervention vs. medical therapy for patients with stable coronary lesions: meta-analysis of individual patient data. Eur Heart J. 2019 Jan 07;40(2):180-186.
13. Tanaka A, Giustino G, Briede I, Sawaya FJ, Daemen J, Kawamoto H, Meliga E, D'Ascenzo F, Cerrato E, Stefanini GG, Capodanno D, Mangiameli A, Templin C, Erglis A, Morice MC, Mehran R, Van Mieghem NM, Nakamura S, De Benedictis M, Pavani M, Varbella F, Pisaniello M, Sharma SK, Tamburino C, Tchetche D, Colombo A, Chieffo A., DELTA 2 Investigators. New-generation drug-eluting stents for left main coronary artery disease according to the EXCEL trial enrollment criteria: Insights from the all-comers, international, multicenter DELTA-2 registry. Int J Cardiol. 2019 Apr 01;280:30-37.
14. Konigstein M, Ben-Yehuda O, Smits PC, Love MP, Banai S, Perlman GY, Golomb M, Ozan MO, Liu M, Leon MB, Stone GW, Kandzari DE. Outcomes Among Diabetic Patients Undergoing Percutaneous Coronary Intervention With Contemporary Drug-Eluting Stents: Analysis From the BIONICS Randomized Trial. JACC Cardiovasc Interv. 2018 Dec 24;11(24):2467-2476.
15. Chen S, Redfors B, Liu Y, Vrolix M, Macaya C, Ben-Yehuda O, Kappetein AP, Sabik JF, Serruys PW, Stone GW. Outcomes of patients with and without baseline lipid-lowering therapy undergoing revascularization for left main coronary artery disease: analysis from the EXCEL trial. Coron Artery Dis. 2019 Mar;30(2):143-149.
16. Morice MC, Urban P, Greene S, Schuler G, Chevalier B. Why are we still using coronary bare-metal stents? J Am Coll Cardiol. 2013 Mar 12;61(10):1122-3.
17. Liu R, Xiong F, Wen Y, Ma YL, Yao Y, Gao Z, Xu B, Yang YJ, Qiao SB, Gao RL, Yuan JQ. Comparison of Efficacy and Safety between First and Second Generation Drug-eluting Stents in Patients with Stable Coronary Artery Disease: A Single-center Retrospective Study. Chin Med J (Engl). 2017 Jul 20;130(14):1654-1661.
18. Borhani S, Hassanajili S, Ahmadi Tafti SH, Rabbani S. Cardiovascular stents: overview, evolution, and next generation. Prog Biomater. 2018 Sep;7(3):175-205.
19. Baydoun H, Jabbar A, Nakhle A, Irimpen A, Patel T, Ward C. Revascularization of Left Main Coronary Artery. Cardiovasc Revasc Med. 2019 Nov;20(11):1014-1019.
20. Gori T, Polimeni A, Indolfi C, Räber L, Adriaenssens T, Münzel T. Predictors of stent thrombosis and their implications for clinical practice. Nat Rev Cardiol. 2019 Apr;16(4):243-256.
21. Zheng C, Kang J, Park KW, Han JK, Yang HM, Kang HJ, Koo BK, Kim HS. The Predictors of Target Lesion Revascularization and Rate of In-Stent Restenosis in the Second-Generation Drug-Eluting Stent Era. J Interv Cardiol. 2019;2019:3270132.
22. Dhillon AS, Narayanan MR, Tun H, Hindoyan A, Matthews R, Mehra A, Shavelle DM, Clavijo LC. In-Hospital Outcomes of Rotational Atherectomy in High-Risk Patients With Severely Calcified Left Main Coronary Artery Disease: A Single-Center Experience. J Invasive Cardiol. 2019 Apr;31(4):101-106.
23. Tadano Y, Kotani JI, Kashima Y, Hachinohe D, Watanabe T, Sugie T, Kaneko U, Kobayashi K, Kanno D, Fujita T. Predictors of clinical outcomes after coronary implantation of bioresorbable polymer sirolimus-eluting Ultimaster stents in all-comers: A report of 1,727 cases. Catheter Cardiovasc Interv. 2019 Jul 01;94(1):91-97.
24. Varenhorst C, Lindholm M, Sarno G, Olivecrona G, Jensen U, Nilsson J, Carlsson J, James S, Lagerqvist B. Stent thrombosis rates the first year and beyond with new- and old-generation drug-eluting stents compared to bare metal stents. Clin Res Cardiol. 2018 Sep;107(9):816-823.

25. Kereiakes DJ, Cannon LA, Dauber I, Ball M, Bertolet B, Foster M, Nersesov AY, Underwood PL, Allocco DJ, Dawkins KD. Long-term follow-up of the platinum chromium TAXUS Element (ION) stent: The PERSEUS Workhorse and Small Vessel trial five-year results. Catheter Cardiovasc Interv. 2015 Nov 15;86(6):994-1001.
26. Kedhi E, Stone GW, Kereiakes DJ, Serruys PW, Parise H, Fahy M, Simonton CA, Sudhir K, Sood P, Smits PC. Stent thrombosis: insights on outcomes, predictors and impact of dual antiplatelet therapy interruption from the SPIRIT II, SPIRIT III, SPIRIT IV and COMPARE trials. EuroIntervention. 2012 Sep;8(5):599-606.
27. de Ribamar Costa J, Abizaid A, Bartorelli AL, Whitbourn R, Jepson N, Perin M, Steinwender C, Stuteville M, Ediebah D, Sudhir K, Serruys PW. One-year clinical outcomes of patients treated with everolimus-eluting bioresorbable vascular scaffolds versus everolimus-eluting metallic stents: a propensity score comparison of patients enrolled in the ABSORB EXTEND and SPIRIT trials. EuroIntervention. 2016 Nov 20;12(10):1255-1262.
28. Doros G, Massaro JM, Kandzari DE, Waksman R, Koolen JJ, Cutlip DE, Mauri L. Rationale of a novel study design for the BIOFLOW V study, a prospective, randomized multicenter study to assess the safety and efficacy of the Orsiro sirolimus-eluting coronary stent system using a Bayesian approach. Am Heart J. 2017 Nov;193:35-45.
29. Kandzari DE, Mauri L, Koolen JJ, Massaro JM, Doros G, Garcia-Garcia HM, Bennett J, Roguin A, Gharib EG, Cutlip DE, Waksman R., BIOFLOW V Investigators. Ultrathin, bioresorbable polymer sirolimus-eluting stents versus thin, durable polymer everolimus-eluting stents in patients undergoing coronary revascularisation (BIOFLOW V): a randomised trial. Lancet. 2017 Oct 21;390(10105):1843-1852.
30. Kereiakes DJ, Meredith IT, Masotti M, Carrié D, Moreno R, Erglis A, Mehta SR, Elhadad S, Berland J, Stein B, Airaksinen J, Jobe RL, Reitman A, Janssens L, Christen T, Dawkins KD, Windecker S. Safety and efficacy of a bioabsorbable polymer-coated, everolimus-eluting coronary stent in patients with diabetes: the EVOLVE II diabetes substudy. EuroIntervention. 2017 Mar 20;12(16):1987-1994
31. Kereiakes DJ, Meredith IT, Windecker S, Lee Jobe R, Mehta SR, Sarembock IJ, Feldman RL, Stein B, Dubois C, Grady T, Saito S, Kimura T, Christen T, Allocco DJ, Dawkins KD. Efficacy and safety of a novel bioabsorbable polymer-coated, everolimus-eluting coronary stent: the EVOLVE II Randomized Trial. Circ Cardiovasc Interv. 2015 Apr;8(4)
32. Konishi A, Ho M, Shirai Y, Shirato H. First Approval of Improved Medical Device Conditional on Use-Result Survey in Japan - Regulatory Review of Polymer-Free Drug-Coated BioFreedom Coronary Stent. Circ J. 2018 May 25;82(6):1487-1490.
33. Waksman R, Piegari GN, Kabour A, Cannon L, Wang J, Adams G, Solankhi N, Smeglin A, Kereiakes DJ, Leiboff R, Spad MA, Torguson R, Chandra N, Bastian R, DeGroot J, Kayo MW, Stoll HP, Garcia-Garcia HM. Polymer-free Biolimus A9-coated stents in the treatment of de novo coronary lesions with short DAPT: 9-month angiographic and clinical follow-up of the prospective, multicenter BioFreedom USA clinical trial. Cardiovasc Revasc Med. 2017 Oct-Nov;18(7):475-481.
34. Garot P, Morice MC, Tresukosol D, Pocock SJ, Meredith IT, Abizaid A, Carrié D, Naber C, Iñiguez A, Talwar S, Menown IBA, Christiansen EH, Gregson J, Copt S, Hovasse T, Lurz P, Maillard L, Krackhardt F, Ong P, Byrne J, Redwood S, Windhövel U, Greene S, Stoll HP, Urban P., LEADERS FREE Investigators. 2-Year Outcomes of High Bleeding Risk Patients After Polymer-Free Drug-Coated Stents. J Am Coll Cardiol. 2017 Jan 17;69(2):162-171.
35. Pavasini R, Serenelli M, Gallo F, Bugani G, Geraci S, Vicinelli P, Campo G. Effectiveness and safety of the ABSORB bioresorbable vascular scaffold for the treatment of coronary artery disease: systematic review and meta-analysis of randomized clinical trials. J Thorac Dis. 2017 Aug;9(Suppl 9):S887-S897.
36. de Hemptinne Q, Picard F, Ly HQ, Ibrahim R, Asgar AW, de Guise P, Doucet S, Dorval JF, Marquis-Gravel G, Levi M, L-L'allier P, Tanguay JF. Long-term outcomes of bioresorbable vascular scaffold in ST-elevation myocardial infarction. Acta Cardiol. 2018 Jun;73(3):276-281.
37. Worthley SG, Abizaid A, Kirtane AJ, Simon DI, Windecker S, Brar S, Meredith IT, Shetty S, Sinhal A, Almonacid AP, Chamié D, Maehara A, Stone GW., RevElution Investigators. First-in-Human Evaluation of a Novel Polymer-Free Drug-Filled Stent: Angiographic, IVUS, OCT, and Clinical Outcomes From the RevElution Study. JACC Cardiovasc Interv. 2017 Jan 23;10(2):147-156.
38. Shlofmitz E, Shlofmitz R, Lee MS. Orbital Atherectomy: A Comprehensive Review. Interv Cardiol Clin. 2019 Apr;8(2):161-171.
39. Allen DW, Kaul P. Atherectomy and Specialty Balloons in Percutaneous Coronary Intervention. Curr Treat Options Cardiovasc Med. 2019 Mar 04;21(3):13.