Hindawi
International Journal of Polymer Science
Volume 2018, Article ID 3891686, 7 pages
https://doi.org/10.1155/2018/3891686

Review Article

The Surface Modification Methods for Constructing Polymer-Coated Stents

Yanqin Fan, Xiang Li, and Ruijie Yang

Department of the Cardiology, Beijing Geriatric Hospital, Beijing 100095, China

Correspondence should be addressed to Yanqin Fan; njr_sr@163.com

Received 25 January 2018; Revised 6 April 2018; Accepted 24 April 2018; Published 3 June 2018

Academic Editor: Shunsheng Cao

Copyright © 2018 Yanqin Fan et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Implanting a metal stent plays a key role in treating cardiovascular diseases. However, the high corrosion rate of metal-based devices severely limits their practical applications. Therefore, how to control the corrosion rate is vital to take full advantages of metal-based materials in the treatment of cardiovascular diseases. This review details various methods to design and construct polymer-coated stents. The techniques are described and discussed including plasma deposition, electrospinning, dip coating, layer-by-layer self-assembly, and direct-write inkjet. Key point is provided to highlight current methods and recent advances in hindering corrosion rate and improving biocompatibility of stents, which greatly drives the rising of some promising techniques involved in the ongoing challenges and potential new trends of polymer-coated stents.

1. Introduction

Developing technologies is an urgent need to treat coronary artery diseases induced by generic factors and dietary habits [1, 2]. Among them, cardiovascular disease has being listed as a major cause of death and morbidity globally based on the status report of noncommunicable diseases in the world [1, 3–7]. Atherosclerosis, as a chronic inflammation with slow progressive buildup of lipids and macrophages within the arterial wall, is the primary contributor to myocardial infarctions and atherosclerotic plaque rupture [1, 8]. In comparison with an open-heart surgery, angioplasty exhibits more benefits to patients and has been extensively employed to treat atherosclerosis by implanting an antithrombogenic agent-coated stent into the infected lesion in order to maintain an artery open after balloon angioplasty [3, 9]; moreover, general anesthesia is unnecessary for patients. In the long run, however, the migration of smooth muscle cell will be stimulated under such a stent implantation, while the atheroma thin layer is subjected to rupture, leading to thrombosis and restenosis [9, 10]. Undoubtedly, an ideal cardiovascular implant should meet the good biocompatibility and high mechanical strength at least [11], in which undue host response or adverse clinical outcomes will not be happened [12, 13]. However, the enhanced incidences of thrombosis, restenosis, and fibromuscular proliferation are hard to be avoided in the face of vascular endothelium injury caused by stent implantation [14].

The premier arterial stents usually use bare metal as scaffolds. Even though the original bare metal stents are epoch-making at the time, their drawbacks are quick occurrence of restenosis and renarrowing of the lumen [3]. The experiments evidence that stents may be subjected to an event known as "late stent thrombosis" that happens one or more years of poststenting, where the blood clots inside the stent [3, 15]. To tackle these challenges, the concept of drug-eluting stents (DESs) was introduced to restrain the occurrence of restenosis and thrombosis by allowing the release of the drug to be gradual and permitting the drug delivery to be sustained over many weeks [3, 16]. Though DESs have achieved great success, material-related problems still exist in the treatment of cardiovascular diseases [17]. An outstanding problem is the lack of blood compatibility, in other words, when these stent implantation devices are confronted to blood directly, the accumulation of a blood clot or thrombus occurs on the surface of these devices [17, 18]. In some cases, the thrombus can directly impair the function of the device, or a piece of the thrombus can embolize and cause life-

threatening problem downstream [17]. For these, many functional surfaces of implantation devices with nonfouling chemical groups [19] and/or anticoagulants [20] have been devoted to improve the blood compatibility of biomaterials, suppressing the protein and platelet deposition.

As continued breakthroughs have been reported in polymer-based materials for cardiovascular diseases in the last several years, a new and comprehensive review is necessary for constructing polymer-based implantation materials, which will further strengthen the treatment of cardiovascular diseases we are currently facing. The main aim of this review is to demonstrate and share the recent advances in the construction of polymer-based coating for cardiovascular stent materials and tackle the major challenges and technological hurdles, providing potential solutions and future directions for the development of polymer-coated stents.

2. Surface Modification Strategies

Magnesium-based materials have been evidenced to be leading metallic materials for the treatment of cardiovascular diseases because of their degradability and resemblance to human cortical bone [21]. However, the fast decomposition rate and accumulation of hydrogen gas upon degradation severely limit their clinical application [22]. Clearly, controlling the corrosion rate is required to make use of magnesium and its alloy materials feasible for surgical implantation. Lots of methods have been introduced to hinder corrosion rate of magnesium-based materials by surface modification methods including plasma anodization [23], microarc oxidation [24], as well as polymer coating [25, 26]. Among them, polymer coating not only is potential to corrosion resistance, but also can act as a drug reservoir [3, 27, 28]. More importantly, this technique holds the ability to be functionalized with various biomolecules including poly(lactic-co-glycolic acid) and poly(l-lactide) acid [22]. In brief, polymer coating metallic stents are having the aim to "encapsulate" the substrate in order to hinder the possible postoperative adverse effects caused by implant devices [29–31]. Numerous methods have been introduced for the polymer coating onto metallic substrates; each has its own unique feature. This section will focus on discussing surface modification methods for the construction of polymer-based coating onto the cardiovascular stents.

2.1. Plasma Deposition. It is well known that blood interactions with stent surfaces are initiated by plasma protein adsorption, followed by the arrival of the platelet at the interface, indicating that protein adsorption plays a decisive role in tuning the platelet response and subsequent hemocompatibility [32]. Therefore, the polymer coating itself on stent biomaterials must be strongly antithrombogenic and good biocompatible. Plasma deposition strategy has been widely employed to prepare the bioactivation of materials by utilizing carbon precursor gases [33, 34]. Clearly, incorporating natural compounds of native tissues is a more profitable host tissue response [35, 36]. Moreover, the method exhibits the potential to tailor polymer coating to meet specific needs [33]. For example, it is easy for plasma technique to modulate the coating chemical composition including surface carboxyl, hydroxyl, amine, or nitrogen-rich functional groups, while the functions of the underlying implant materials are not damaged through an optimal selection of gaseous mixtures [33, 37–39].

A typical plasma deposition can be described [32], in which the tungsten needle is tightly encapsulated in a quartz tube with copper coils wrapped around the end of the tube acting as the ground electrode. The high-voltage electrode is connected to a DC power supply under the discharge voltage. After that, the liquid monomer is placed in a bubbler and argon as the working gas to produce the plasma. The mixed gas is bled through the quartz tube, and a cold plasma plume is generated. Finally, the metal alloy substrate is placed under the tube nozzle during deposition of the plasma-polymerized coating [32]. In short, this technique mainly involves the bombardment of the targeted coating material, and then the evaporated material is transported to a substrate [40]. Polymer-based materials for stents via plasma treatment have been widely reported. For example, Giol et al. bound protein layer onto poly(ethylene terephthalate) (PET) substrate for cardiovascular implants using a plasma pretreatment[31]. Santos and co-workers constructed plasma-activated coatings with the high mechanical properties using plasma deposition technique [33]. Recently, Jurak et al. reported mixed chitosan/phospholipid coatings on the air plasma-activated PET surface [35]. However, this method is hard to tailor the coated polymer material due to the wasted material during the process of transportation. Furthermore, the denaturing of biomaterials is also a limitation because of its high temperature of operation [40]. Therefore, there is of great interest to overcome the disadvantages of the plasma process, to ascertain the main physical quantities, and to expound the coating growth mechanisms for the preparation of polymer coated materials in the cardiovascular material field.

2.2. Electrospinning Technique. Electrospinning is a unique and versatile technique using an applied voltage for liquid atomization process, in which the atomized droplets are extremely small, monodisperse, and highly charged, leading to high deposition efficiency for polymer coating onto the desired substrates. This technique is able to provide unlimited potential to achieve vascular graft prostheses by tailoring applied electrospinning conditions [40, 41]. Therefore, this technique can offer polymeric scaffolds with similar mechanical properties comparable to native vascular tissues [41]. Excitedly, this process is more favorable to develop polymeric fibers with various diameters with nm to μm scale and a mesh-like coating with high porosity for vascular graft prostheses [40, 41]. As a result, electrospinning method undergoes fast development in recent years because it can be employed for creating functional implantation materials with different morphologies and multidimensional architectures [11]. For example, Wang et al. [30] introduced a facile method to prepare surface metallic cardiovascular stents with complex tridimensional structures via electropolymerization of dopamine. Their further investigation demonstrated that this strategy manifested an enhanced deposition rate in

comparison to the classical approach. Sauter et al. [27] prepared a thin fibrous encasement consisting of oligo(p-dioxanone) and oligo(ε-caprolactone) segments by electrospinning for metallic stents. The as-synthesized linear multiblock copolymer was allowed to design their degradability, thermal and mechanical properties by changing molecular parameters. Recently, Bakola et al. [3] prepared fibrous stents by using polycaprolactone and polylactic acid as drug delivery nanosystems via electrospinning process and found that this scaffold was able to control the pharmacokinetics in vitro, resulting in a valuable tool towards cardiovascular treatment. The typical electrospinning process is illustrated in Figure 1. First, a charged jet of polymer solution is created by using an electric field. After that, the solvent evaporates leaving behind a charged fiber that is able to be electrically deflected or collected on a metal substrate as this jet travels in air [41].

Because of these advantages, it is concluded that electrospinning is now one of the most widely investigated methods for constructing stents of the cardiovascular system, envisioning that new achievements in electrospinning technique will be achieved with the advanced in nanotechnology and biotechnology. Unfortunately, low coating yields, monosubstrate, and poor precision for patterning are its main drawbacks because electrospray is extremely sensitive to the physical properties of liquid and the electric field in the vicinity of the emitter tip [40, 42]. Moreover, the polymer coating with multidimensional structures is hard to achieve via this technique. Therefore, the combination of other methods is promising direction to work out these limitations.

2.3. Dip Technique. Compared with electrospinning method, the dip coating is the earliest, simplest, and most economical technique to produce polymer thin films because of the limited amount of polymer solution and equipment necessary [43]; therefore, dip coating is extensively used to apply a buildup layer for research purposes. For example, Abdalhay et al. [44] utilized dip coating technique to coat the magnesium substrate with poly(lactic acid), substantially hindering its corrosion rate. Yang and coworkers [45] introduced a dip coating method to develop a multifunctional coating onto mirror polished 316L SS by copolymerization of dopamine and hexamethylenediamine (PDAM/HD). The results showed that the multifunctional vascular stent presented excellent tissue compatibility. Chen et al. [12] prepared the multifunctional phosphorylcholine/peptide (PC/PT) coating containing phosphorylcholine groups and endothelial progenitor cell- (EPC-) specific peptides on Ti surfaces via dip coating technique and found that the PC/PT coating not only manifested greatly enhancement in blood compatibility, but also induced considerable enhancement in EPC adhesion and proliferation, substantially hindering smooth muscle cell adhesion and proliferation.

From the view of synthetic procedure, although it only consists of three basic steps: immersion, dwell, and withdrawal [46], lots of experimental parameters severely influence the layer thickness and final characteristics of polymer coating such as polymer concentration, solvent properties, viscosity, dwell time, the number of dipping-withdrawal cycles, and immersion/withdrawn speed. Therefore, the latitude of spatial control and the switch of coating materials are hard to be realized [40, 46]. Undoubtedly, finding the optimal condition is very important for the construction of polymer-coated stents with controllable morphology and structure through dip coating technique. Moreover, it has been proved that the loading amount of polymer coating through dip coating method is usually less than that by electrospinning technique, especially for drug loading on stent surface [46].

2.4. Layer-by-Layer Self-Assembly. Self-assembly technique is to autonomously drive molecules into designed patterns or structures in the absence of human intervention. Evidently, organizing themselves into desired patterns and functions is a decisive procedure for the construction of components. Layer-by-layer (LBL), as a versatile method, can create multilayer polymer films with tunable composition and film thickness and can explore the ordered coating without the need for high-precision patterning equipment [47, 48]. Although this technique involves electrostatic and nonelectrostatic interactions or a combination of both, the majority of the works reported are mainly paid to LBL via electrostatic interactions [49]. As an efficient technique, the LBL method can play a pivotal role in producing polymer thin films for the surface coating implants [40, 49, 50]. For instance, Wang et al. [50] fabricated fibronectin-terminated multilayer films consisted of heparin and vascular endothelial growth factor on titanium substrates via LBL method. The as-synthesized multilayer films coated on titanium disks provided good blood compatibility and endothelialization. Lin et al. [51] constructed a hydrogel-like polyelectrolyte multilayer composed of polysaccharide heparin and chitosan via layer-by-layer self-assembly. Recently, Silva and co-workers [49] further reported the multilayered hollow tubes by combining LBL and template leaching.

Because of the possibility in maintaining the biomacromolecular activity and the flexibility, LBL strategy can produce tubular structures with controlled properties and can control the nature of the as-synthesized polymer multilayers by simply changing assembly parameters, widely applying to intravascular stent and graft surface modification [51]. Therefore, this technique exhibits an invaluable potential to unite the functionalities of the multicomponents into polymer coating of stent. In the case of LBL assembly, this technique mainly involves in alternating layers of negatively and positively charged coating materials [40, 47, 48]. Figure 2 demonstrates the typical process for the preparation of the polymer multilayers coating on substrates. First, the cleaned titanium substrate is immersed in polycation (e.g., PEI) to reach a stable positive charge; after removing unconsolidated polycation, the positive substrate is dipped into polyanion solution to obtain a negative charge, followed by the same rinsing procedures. Clearly, the adsorption of each polyelectrolyte will lead to a reversal of surface charge, driving the subsequent adsorption of another oppositely charged layer. Finally, multilayer film can be obtained by repeating the deposition process. Although LBL assembly has been proved to be highly effective in designing multilayer

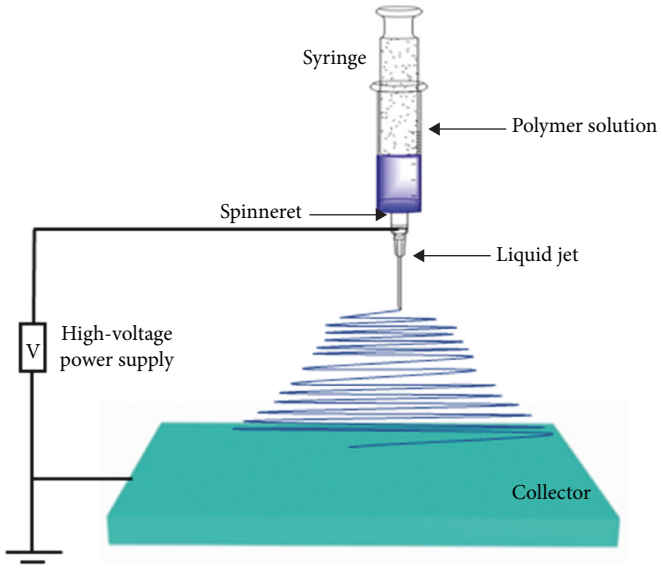


Figure 1: The typical examples of micropore fabrication techniques electrospinning.

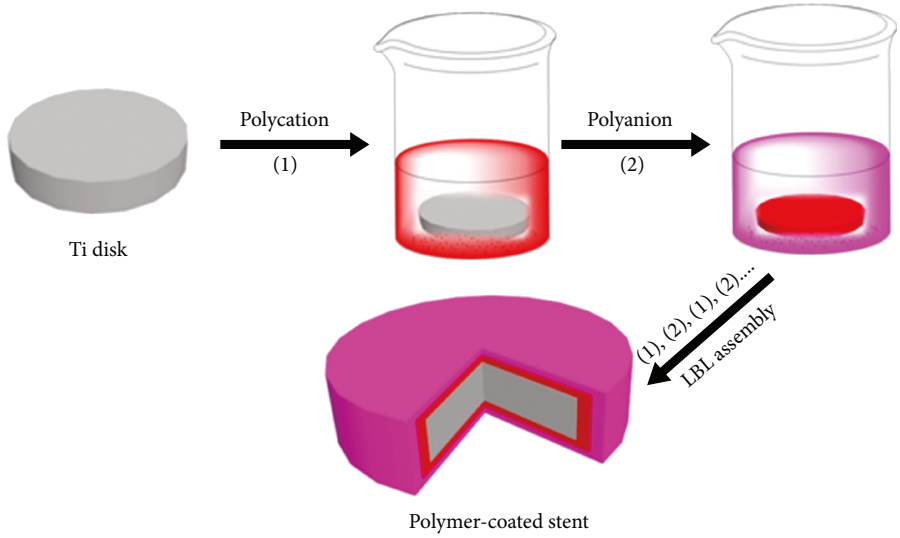


Figure 2: Scheme for the preparation of multilayers coating on substrate via layer-by-layer (LBL) self-assembly.

nanostructured coatings, it cannot assemble precise and localized coatings onto multidimensional complex structures, which is vital to coat the vascular stent with an intricate geometry [40]. Therefore, this technique has not been yet developed into a feasible method, and it will be worthwhile to further investigate it.

2.5. The Direct-Write Inkjet. For drug-eluting stents, spray coating and dip technique are yet the main strategies. As aforementioned, spray coating technique uses a nozzle to spray polymer-drug solution-forming droplets on a rotated substrate [52], while dip coating immerses the cleaned stent into polymer-drug solution; after several repetitions, the suitable amount of drug is deposited [53]. However, the loss of waste solution, low coating rate, and the time-consuming processing are their disadvantages. By contrast, the direct-write inkjet technique exhibits several advantages including flexibility, low cost, and high coating yields by controlling sample aspiration from the dispenser nozzle, far beyond spray coating and dip coating methods [54, 55]. Especially, this process can precisely tailor droplet size of the polymer-drug, which patterns multiple analytes simultaneously using independent cartridges, decreases the pollution of the coated material, and promotes release profiles of drug [40, 52, 55]. Therefore, numerous materials including functional polymers, biodegradable materials, suspensions, and biological agents can be processed via inkjet printing. For example, Feyssa et al. [55] introduced an efficient and versatile technique to pattern functional antibodies within polymer-based microfluidic platform. Perkins et al. [54] deposited

polymeric coatings on magnesium alloy by utilizing the direct-write printing method in order to enhance metallic biocompatibility and inhibit its corrosion rate. In recent studies, Mau and coworkers [56] investigated drug deposition into microsized reservoirs using a drop-on-demand inkjet print head. They further pointed out that the wettability of the surface played a vital role for drug deposition into microsized reservoirs. Scoutaris et al. [53] used biodegradable polymeric coatings with the antiproliferative drugs simvastatin and paclitaxel on coronary metal stents. The results showed that coating yields were as high as 56 % and 79 % through employing inkjet coating on Cypher® and Presillion®, respectively. The typical system of inkjet printing consists of the wash station, the dispenser, and the dispense control system, in which the amount of aspiration is controlled via an accurate flow sensor while a stroboscope ensures that the dispenser ejects the droplets.

From the procedure of inkjet printing technology, this process mainly involves the printing of polymeric microparticles with tunable droplets, oral films, coating of transdermal microneedle surfaces, and stent coating of drug-loaded polymeric layers [53], which considerably drives its applications in preparing lots of medical devices including drug-eluting stents for cardiovascular treatment. However, the challenges of this technique are yet faced [56]: (1) the biological agents which are to be deposited need to be dissolved in appropriate solvents; (2) the printability of the dissolution is a vital factor for polymer-drug coating; and (3) controlling evaporation speed is required for the development of drug-loaded microreservoirs. What is worse, it is challenging for producing tissue/organ analogs with fully biological characteristics and complex microstructure [57]. Clearly, exploring more high-performance bioinks and high-resolution bioprinters is urgent for the treatment of cardiovascular diseases. There is much promise that 3D bioprinting strategies associated with other tissue engineering, biofabrication, and/or biological techniques will drive considerable enhancement for the applications of cardiovascular tissue engineering and further clinical uses.

Besides the aforementioned polymer coating methods, chemical vapor deposition (CVD) can deposit thin films onto the surface of the stents by using reactive chemicals without significantly affecting their bulk properties [58], especially for plasma-driven CVD techniques. However, CVD method does not hold functional groups to attach biomolecules; therefore, it is required to further treatment of stents materials with plasma or chemicals, introducing biomolecule attachment [58]. For this, other chemical modification methods such as low-pressure plasma treatments, plasma vapor deposition, and grafting techniques are also used to functionalize the surface of the materials in order to enhance the biocompatibility of stent materials.

3. Outlook and Concluding Remarks

This review has detailed current strategies employed to construct polymer coating onto metal-based stents. At the same time, how to efficiently meet such challenges we are facing is also summarized and discussed. It is anticipated that this understanding will continue to evolve the processes and provide practical methods. Furthermore, combining multistrategies (e.g., electrospinning and plasma coating) is possible to explore interesting and even exciting techniques for finely controlling structural, mechanical, and surface properties of polymer coating onto metal-based stents.

Afore-mentioned methods have not yet been perfected to design multifunctional polymer-coated stents, especially for the small-sized coronary stents with complex shape and structure. Moreover, these available techniques have been used to a limited extent because of multisteps processes and poor stability. It is envisioned that this review can help to optimize existed methods and to explore new techniques, which better construct multifunctional polymer-coated stents.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] J. W. H. Wennink, Y. Liu, P. I. Mäkinen et al., "Macrophage selective photodynamic therapy by meta-tetra(hydroxyphenyl)chlorin loaded polymeric micelles: a possible treatment for cardiovascular diseases," *European Journal of Pharmaceutical Sciences*, vol. 107, pp. 112–125, 2017.

[2] Y.-J. Wang, M. Larsson, W.-T. Huang et al., "The use of polymer-based nanoparticles and nanostructured materials in treatment and diagnosis of cardiovascular diseases: recent advances and emerging designs," *Progress in Polymer Science*, vol. 57, pp. 153–178, 2016.

[3] V. Bakola, V. Karagkiozaki, F. Pappa et al., "Drug delivery nanosystems for cardiovascular stents," *Materials Today: Proceedings*, vol. 4, no. 7, pp. 6869–6879, 2017.

[4] Y. Fan, Q. Yang, H. Han et al., "Clinical characteristics and causes analysis of atrial fibrillation in elderly patients," *Journal of Cardiovascular & Pulmonary Diseases*, vol. 35, no. 9, pp. 715–718, 2016.

[5] Y. Fan, Q. Yang, J. Lv, X. Pang, and X. Chen, "Clinical characteristics analysis of heart failure in elderly patients," *Journal of Cardiovascular&Pulmonary Diseases*, vol. 34, no. 6, pp. 444–451, 2015.

[6] V. E. Bosio, J. Brown, M. J. Rodriguez, and D. L. Kaplan, "Biodegradable porous silk microtubes for tissue vascularization," *Journal of Materials Chemistry B*, vol. 5, no. 6, pp. 1227–1235, 2017.

[7] World Health Organization, *Global Status Report on Noncommunicable Diseases*, vol. 1, World Health Organization, Geneva, Switzerland, 2014.

[8] P. Libby, P. M. Ridker, and A. Maseri, "Inflammation and atherosclerosis," *Circulation*, vol. 105, no. 9, pp. 1135–1143, 2002.

[9] B. Oh and C. H. Lee, "Advanced cardiovascular stent coated with nanofiber," *Molecular Pharmaceutics*, vol. 10, no. 12, pp. 4432–4442, 2013.

[10] R. A. Byrne, M. Joner, T. Tada, and A. Kastrati, "Restenosis in bare metal and drug-eluting stents: distinct mechanistic insights from histopathology and optical intravascular imaging," *Minerva Cardioangiologica*, vol. 60, no. 5, pp. 473–489, 2012.

[11] W. Lu, J. Sun, and X. Jiang, "Recent advances in electrospinning technology and biomedical applications of electrospun fibers," *Journal of Materials Chemistry B*, vol. 2, no. 17, pp. 2369–2380, 2014.

[12] H. Chen, Y. Zhao, K. Xiong et al., "Multifunctional coating based on EPC-specific peptide and phospholipid polymers for potential applications in cardiovascular implants fate," *Journal of Materials Chemistry B*, vol. 4, no. 48, pp. 7870–7881, 2016.

[13] G. Li, P. Yang, W. Qin, M. F. Maitz, S. Zhou, and N. Huang, "The effect of coimmobilizing heparin and fibronectin on titanium on hemocompatibility and endothelialization," *Biomaterials*, vol. 32, no. 21, pp. 4691–4703, 2011.

[14] Q. Li, Z. Wang, S. Zhang et al., "Functionalization of the surface of electrospun poly(epsilon-caprolactone) mats using zwitterionic poly(carboxybetaine methacrylate) and cell-specific peptide for endothelial progenitor cells capture," *Materials Science and Engineering: C*, vol. 33, no. 3, pp. 1646–1653, 2013.

[15] V. Karagkiozaki, P. G. Karagiannidis, N. Kalfagiannis et al., "Novel nanostructured biomaterials: implications for coronary stent thrombosis," *International Journal of Nanomedicine*, vol. 7, pp. 6063–6076, 2012.

[16] S. McGinty, "A decade of modelling drug release from arterial stents," *Mathematical Biosciences*, vol. 257, pp. 80–90, 2014.

[17] D. E. Heath, "Promoting endothelialization of polymeric cardiovascular biomaterials," *Macromolecular Chemistry and Physics*, vol. 218, no. 8, article 1600574, 2017.

[18] D. Williams, *Essential Biomaterials Science*, Cambridge University Press, Cambridge, UK, 1st edition, 2014.

[19] D. E. Heath and S. L. Cooper, "Design and characterization of sulfobetaine-containing terpolymer biomaterials," *Acta Biomaterialia*, vol. 8, no. 8, pp. 2899–2910, 2012.

[20] D. Shemesh, I. Goldin, J. Hijazi et al., "A prospective randomized study of heparin-bonded graft (Propaten) versus standard graft in prosthetic arteriovenous access," *Journal of Vascular Surgery*, vol. 62, no. 1, pp. 115–122, 2015.

[21] H. M. Wong, K. W. K. Yeung, K. O. Lam et al., "A biodegradable polymer-based coating to control the performance of magnesium alloy orthopaedic implants," *Biomaterials*, vol. 31, no. 8, pp. 2084–2096, 2010.

[22] X. Gu, Z. Mao, S.-H. Ye et al., "Biodegradable, elastomeric coatings with controlled anti-proliferative agent release for magnesium-based cardiovascular stents," *Colloids and Surfaces B: Biointerfaces*, vol. 144, pp. 170–179, 2016.

[23] C.-E. Barchiche, E. Rocca, C. Juers, J. Hazan, and J. Steinmetz, "Corrosion resistance of plasma-anodized AZ91D magnesium alloy by electrochemical methods," *Electrochimica Acta*, vol. 53, no. 2, pp. 417–425, 2007.

[24] T. S. N. Sankara Narayanan, I. S. Park, and M. H. Lee, "Strategies to improve the corrosion resistance of microarc oxidation (MAO) coated magnesium alloys for degradable implants: prospects and challenges," *Progress in Materials Science*, vol. 60, pp. 1–71, 2014.

[25] A. Strohbach and R. Busch, "Polymers for cardiovascular stent coatings," *International Journal of Polymer Science*, vol. 2015, Article ID 782653, 11 pages, 2015.

[26] M. Sgarioto, R. Adhikari, P. A. Gunatillake et al., "Properties and *in vitro* evaluation of high modulus biodegradable polyurethanes for applications in cardiovascular stents," *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, vol. 102, no. 8, pp. 1711–1719, 2014.

[27] T. Sauter, B. Geiger, K. Kratz, and A. Lendlein, "Encasement of metallic cardiovascular stents with endothelial cell-selective copolyetheresterurethane microfibers," *Polymers for Advanced Technologies*, vol. 26, no. 10, pp. 1209–1216, 2015.

[28] Y. Wang, W. Zhang, J. Zhang, W. Sun, R. Zhang, and H. Gu, "Fabrication of a novel polymer-free nanostructured drug-eluting coating for cardiovascular stents," *ACS Applied Materials & Interfaces*, vol. 5, no. 20, pp. 10337–10345, 2013.

[29] H. Yao, J. Li, N. Li, K. Wang, X. Li, and J. Wang, "Surface modification of cardiovascular stent material 316L SS with estradiol-loaded poly (trimethylene carbonate) film for better biocompatibility," *Polymer*, vol. 9, no. 11, p. 598, 2017.

[30] J.-l. Wang, B.-c. Li, Z.-j. Li et al., "Electropolymerization of dopamine for surface modification of complex-shaped cardiovascular stents," *Biomaterials*, vol. 35, no. 27, pp. 7679–7689, 2014.

[31] E. D. Giol, D. Schaubroeck, K. Kersemans, F. De Vos, S. Van Vlierberghe, and P. Dubruel, "Bio-inspired surface modification of PET for cardiovascular applications: case study of gelatin," *Colloids and Surfaces B: Biointerfaces*, vol. 134, pp. 113–121, 2015.

[32] P. Li, L. Li, W. Wang et al., "Enhanced corrosion resistance and hemocompatibility of biomedical NiTi alloy by atmospheric-pressure plasma polymerized fluorine-rich coating," *Applied Surface Science*, vol. 297, pp. 109–115, 2014.

[33] M. Santos, E. C. Filipe, P. L. Michael, J. Hung, S. G. Wise, and M. M. M. Bilek, "Mechanically robust plasma-activated interfaces optimized for vascular stent applications," *ACS Applied Materials & Interfaces*, vol. 8, no. 15, pp. 9635–9650, 2016.

[34] A. Waterhouse, S. G. Wise, Y. Yin et al., "*In vivo* biocompatibility of a plasma-activated, coronary stent coating," *Biomaterials*, vol. 33, no. 32, pp. 7984–7992, 2012.

[35] M. Jurak, A. E. Wiącek, R. Mroczka, and R. Łopucki, "Chitosan/phospholipid coated polyethylene terephthalate (PET) polymer surfaces activated by air plasma," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 532, pp. 155–164, 2017.

[36] Y. Farhatnia, A. Tan, A. Motiwala, B. G. Cousins, and A. M. Seifalian, "Evolution of covered stents in the contemporary era: clinical application, materials and manufacturing strategies using nanotechnology," *Biotechnology Advances*, vol. 31, no. 5, pp. 524–542, 2013.

[37] Z. Yang, X. Lei, J. Wang et al., "A novel technique toward bipolar films containing alternating nano–layers of allylamine and acrylic acid plasma polymers for biomedical application," *Plasma Processes and Polymers*, vol. 8, no. 3, pp. 208–214, 2011.

[38] B. R. Coad, T. Scholz, K. Vasilev, J. D. Hayball, R. D. Short, and H. J. Griesser, "Functionality of proteins bound to plasma polymer surfaces," *ACS Applied Materials & Interfaces*, vol. 4, no. 5, pp. 2455–2463, 2012.

[39] P. Qi, Y. Yang, K. Xiong et al., "Multifunctional plasma-polymerized film: toward better anticorrosion property, enhanced cellular growth ability, and attenuated inflammatory and histological responses," *ACS Biomaterials Science & Engineering*, vol. 1, no. 7, pp. 513–524, 2015.

[40] J. Perkins, Y. Hong, S. Ye, W. R. Wagner, and S. Desai, "Direct writing of bio-functional coatings for cardiovascular

applications," *Journal of Biomedical Materials Research Part A*, vol. 102, no. 12, pp. 4290–4300, 2014.

[41] J. Kucinska-Lipka, I. Gubanska, H. Janik, and M. Sienkiewicz, "Fabrication of polyurethane and polyurethane based composite fibres by the electrospinning technique for soft tissue engineering of cardiovascular system," *Materials Science and Engineering C*, vol. 46, pp. 166–176, 2015.

[42] A. Jaworek, "Electrospray droplet sources for thin film deposition," *Journal of Materials Science*, vol. 42, no. 1, pp. 266–297, 2007.

[43] A. S. Avishan, "Formulation and testing of biodegradable polymeric coating on zinc wires in cardiovascular stent application," Open Access Master's Thesis, Michigan Technological University, 2017.

[44] A. Abdal-hay, N. A. M. Barakat, and J. K. Lim, "Influence of electrospinning and dip-coating techniques on the degradation and cytocompatibility of Mg-based alloy," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 420, pp. 37–45, 2013.

[45] Y. Yang, P. Qi, F. Wen et al., "Mussel-inspired one-step adherent coating rich in amine groups for covalent immobilization of heparin: hemocompatibility, growth behaviors of vascular cells, and tissue response," *ACS Applied Materials & Interfaces*, vol. 6, no. 16, pp. 14608–14620, 2014.

[46] Y. Liu, W. Wang, G. Acharya, Y.-B. Shim, E. S. Choe, and C. H. Lee, "Advanced stent coating for drug delivery and in vivo biocompatibility," *Journal of Nanoparticle Research*, vol. 15, no. 10, p. 1962, 2013.

[47] S. Cao, J. Chen, and J. Hu, "The fabrication and progress of core-shell composite materials," *Australian Journal of Chemistry*, vol. 62, no. 12, pp. 1561–1576, 2009.

[48] S. Cao, Y. Zhang, L. Zhou et al., "Stimuli-responsive controlled release and molecular transport from hierarchical hollow silica/polyelectrolyte multilayer formulations," *Journal of Materials Chemistry B*, vol. 2, no. 41, pp. 7243–7249, 2014.

[49] J. M. Silva, C. A. Custodio, R. L. Reis, and J. F. Mano, "Multilayered hollow tubes as blood vessel substitutes," *ACS Biomaterials Science & Engineering*, vol. 2, no. 12, pp. 2304–2314, 2016.

[50] H. G. Wang, T. Y. Yin, S. P. Ge et al., "Biofunctionalization of titanium surface with multilayer films modified by heparin-VEGF-fibronectin complex to improve endothelial cell proliferation and blood compatibility," *Journal of Biomedical Materials Research Part A*, vol. 101A, no. 2, pp. 413–420, 2013.

[51] Q. K. Lin, Y. Hou, X. Xu et al., "Anti-CD34 antibody functionalized swollen polymeric coating for endothelial cell rapid selectively capture," *International Journal of Polymeric Materials and Polymeric Biomaterials*, vol. 64, no. 2, pp. 99–103, 2015.

[52] N. Scoutaris, S. Ross, and D. Douroumis, "Current trends on medical and pharmaceutical applications of inkjet printing technology," *Pharmaceutical Research*, vol. 33, no. 8, pp. 1799–1816, 2016.

[53] N. Scoutaris, F. Chai, B. Maurel et al., "Development and biological evaluation of inkjet printed drug coatings on intravascular stent," *Molecular Pharmaceutics*, vol. 13, no. 1, pp. 125–133, 2016.

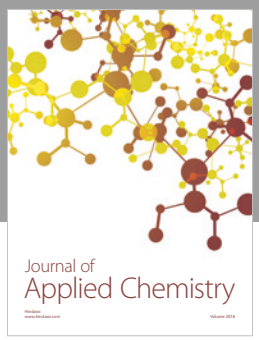
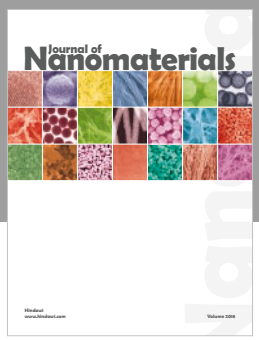
[54] J. Perkins, Z. Xu, C. Smith et al., "Direct writing of polymeric coatings on magnesium alloy for tracheal stent applications," *Annals of Biomedical Engineering*, vol. 43, no. 5, pp. 1158–1165, 2015.

[55] B. Feyssa, C. Liedert, L. Kivimaki, L.-S. Johansson, H. Jantunen, and L. Hakalahti, "Patterned immobilization of antibodies within roll-to-roll hot embossed polymeric microfluidic channels," *PLoS One*, vol. 8, no. 7, article e68918, 2013.

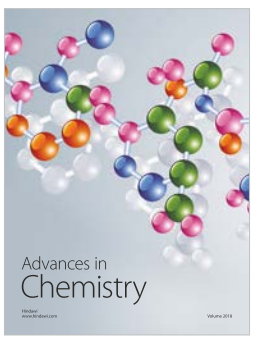
[56] R. Mau, P. Oldorf, R. Peters, and H. Seitz, "Adjusting inkjet printhead parameters to deposit drugs into micro-sized reservoirs," *Current Directions in Biomedical Engineering*, vol. 2, no. 1, pp. 387–390, 2016.

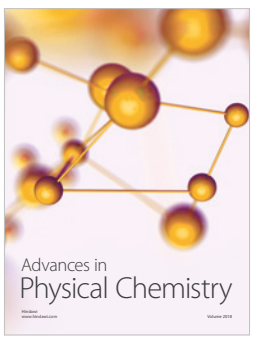
[57] B. Duan, "State-of-the-art review of 3D bioprinting for cardiovascular tissue engineering," *Annals of Biomedical Engineering*, vol. 45, no. 1, pp. 195–209, 2017.

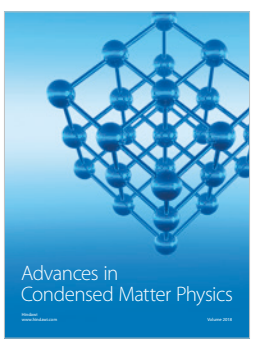
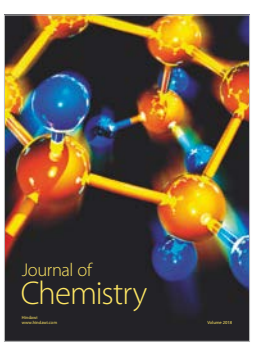
[58] T. Govindarajan and R. Shandas, "A survey of surface modification techniques for next-generation shape memory polymer stent devices," *Polymers*, vol. 6, no. 9, pp. 2309–2331, 2014.

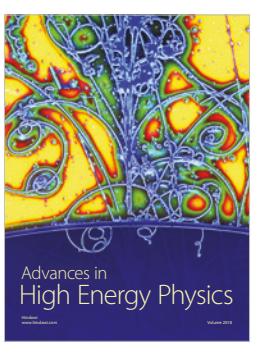

The Scientific
World Journal

Journal of
Applied Chemistry

Journal of
Nanomaterials

Scientifica

International Journal of
Polymer Science

Advances in
Chemistry

Hindawi
Submit your manuscripts at
www.hindawi.com

Advances in
Physical Chemistry

International Journal of
Analytical Chemistry

Advances in
Condensed Matter Physics

Journal of
Chemistry

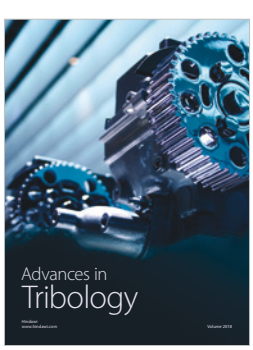
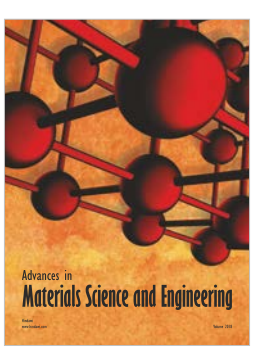
International Journal of
Biomaterials

Advances in
High Energy Physics

Journal of
Engineering

Journal of
Nanotechnology

International Journal of
Corrosion

Journal of
Materials

BioMed
Research International

Advances in
Tribology

Advances in
Materials Science and Engineering