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POLYMER COATED DRUG ELUTED STENT FOR CARDIOVASCULAR DISEASES

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Abstract
Cardiovascular disease (CVD) is one of the serious disease worldwide. Currently top ten cause of death in the world cause due to CVD. CVD includes many conditions like the Coronary Artery Disease (CAD), Ischemic Heart Disease (IHD), and aortic diseases [1]. To overcome this fatal disease many treatments have been introduced in the field of medicine, like angioplasty and the field of interventional cardiology extended its support by the introduction of stent. Stent is a small tube like arrangement that is deployed in the coronary artery after the plaque removal (block), to allow the free flow of blood through the artery. Initially, the stents were made up of metal source like stainless steel, Cobalt and termed as Bare Metal Stents (BMS). The disadvantageous of using these stents include reoccurrence of the plaque and neointimal hyperplasia. In order to overcome these draw backs, Drug Eluting Stents (DES) were introduced which deliver the drug at the site of plaque formation and reduce the multiplication of smooth muscle cell thereby reducing neointimal hyperplasia. Restenosis and thrombosis seems to be problem of stenting irrespective of the material used. Therefore, in the present investigation two different materials, Polypropylene (polymer) is introduce to overcome the stated problem.
Keywords: Polymer, RBC, stent, Cardiovascular disease

1. Introduction

Cardiovascular Disease (CVD) is accounted for nearly 40% of death around the world and in India it is considered as a rapidly growing chronic illness which in the recent years have affected people irrespective of the age. The growth of this disease is influenced by many factors such as aging, modern life style, socio economic status of the population of developing nations and many other interlinking factors[1]. Presently, percutaneous coronary intervention (PCI) is the treatment for CVD[18]. During PCI, an expandable balloon like coronary stent is placed inside the lessoned artery. Arterial injury is an inevitable consequence of all interventional procedures and initiates a cascade of cellular and molecular events resulting in an acute disruption of the endothelial layer [3].Therefore, more research is required on the safety of coronary stents, but side effects, such as late and very late stent-thrombosis and in-stent restenosis, remain problematic which cause the damage of artery.

In this regard, polymers that can release medications, mimic biological functions, or degrade are of tremendous interest for the creation of vascular implants. Therefore, complex biomaterials are

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needed to meet specific requirements to their unique features and biocompatibility. The current evaluation is concentrated on polymers employed as drug-eluting stent (DES) coating matrices and stent platforms, and the investigation is concentrated on RBC, stent, and artery leading to an acute disruption of the endothelial layer [3].Therefore, current research on coronary stent safety is concentrated, yet complications including late and extremely late stent-thrombosis and in-stent restenosis continue to be an issue.

1.1 Atherosclerosis

Atherosclerosis is an inflammatory disease characterized by narrowing of the vessel wall due to amassing of lipids. These medical problems mainly occurs in large and medium sized vessels[11].Initially understood to be a response to injury, atherosclerosis originates from variety of reasons including elevated plasma concentration in Low Density Lipoprotein(LDL), smoking, hyper tension, diabetes[12,13].

The lesion originates in area of damaged endothelium layer where high plasma concentration LDL permeates through it and oxidizes. These oxidized LDL may finally result in plaque which is mainly a calcified part [14, 15].This atherosclerotic lesion eventually narrows down the luminal area obstructing the blood flow. Acute short supply of oxygenated blood to the muscles eventually results in angima, Myocardial Infraction (MI) and heart attack. MI also results due to rupture of plaque[16].

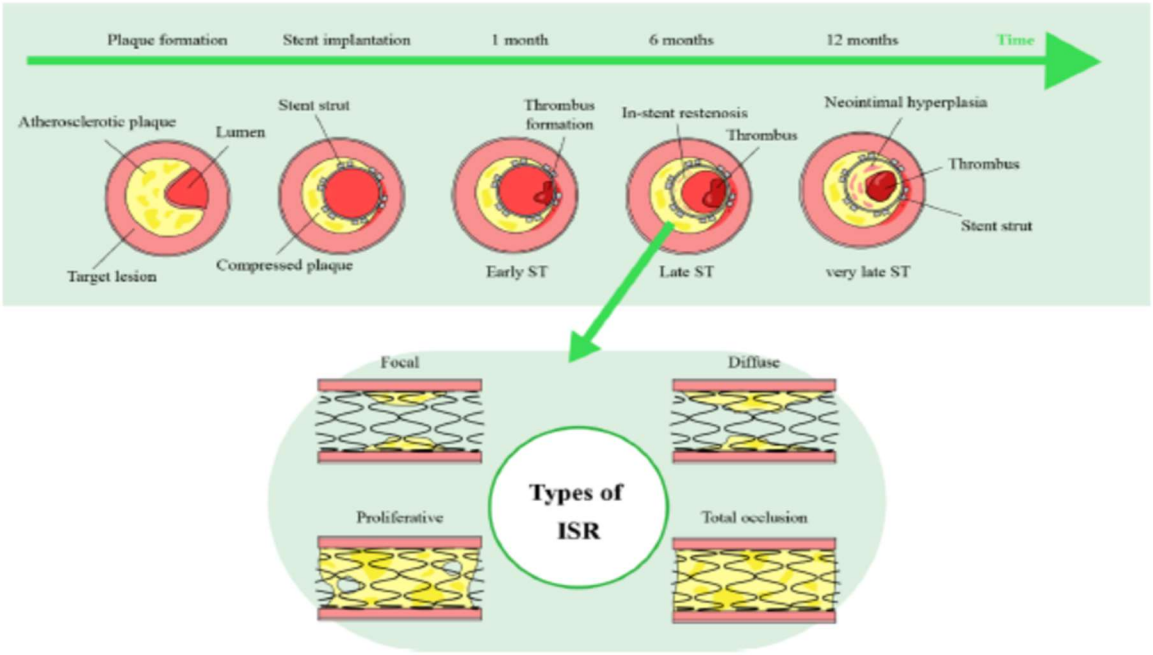

Fig. 1. Mechanisms and types of in-stent restenosis (ISR) and stent thrombosis (ST).

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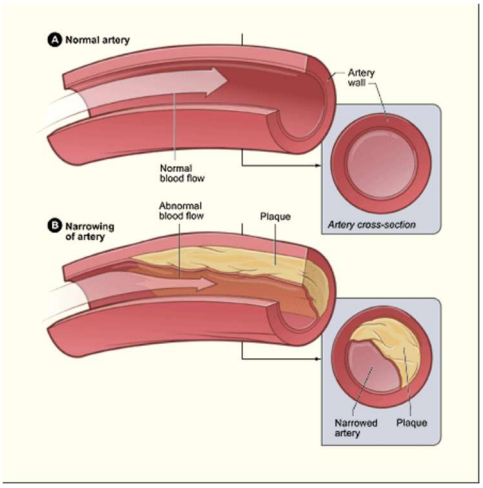

Fig 2. Normal coronary artery and development of atherosclerosis due to plaque deposition [17]

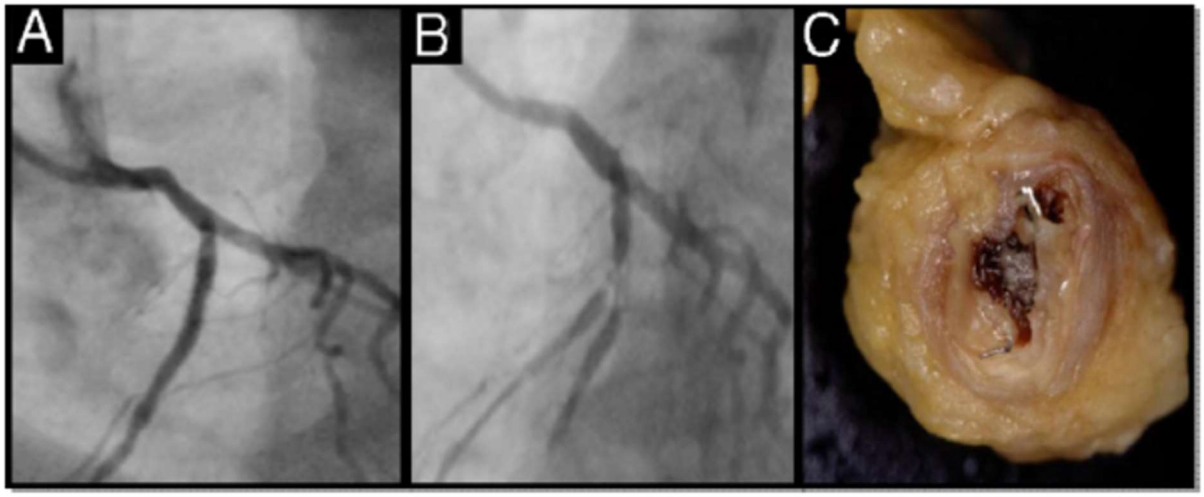

Fig. 3 Stent Thrombosis [7]

1.2 Treatment for diseases:

Early treatment available to treat atherosclerosis is bypass grafting. An alternate blood channel is created to bypass the narrowed region such that sufficient blood is available to distal ends. Beside benefits of lesser risk of CHD symptoms and higher blood pumping capacity post treatment, this strategy poses risks of bleeding, infections and other complications[21].With the advent of minimal invasive medical technology [22], bypass grafting is replaced by Plain Old Balloon Angioplasty(POBA). This method would compress the atherosclerotic lesion by the application of fluid pressure through balloon thus maintain the patency of lumen. Re-narrowing of artery in shortest period of time after angioplasty is overcome by angioplasty by balloon structured stents[23,24].Ever since angioplasty with stents revolutionized the treatment strategy for atherosclerotic lesion there has been large increase in the Percutaneous Coronary Intervention(PCI) performed every year around the world[25].

2. Coronary Stent:

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Coronary stents are typically regarded as permanent implants. An expandable, cylindrical cardiovascular device is inserted endovascularly into a vessel at the time of treatment. The stent is shrunk to a tiny diameter, positioned over an angioplasty balloon catheter, deformed plastically, fixed in place, and creates a scaffold that maintains the artery's openness. The stent is placed in a small blood artery to restore normal blood flow[7].

With the apparent improvements in angiographic and clinical outcomes demonstrated with their use [4,5], coronary stents [3] gradually replaced "plain old balloon angioplasty" (POBA) as the preferred way of performing PCI. Interventional cardiologists now have a large selection of coronary stents to implant as the majority of PCI procedures use one. This selection includes more recent stents such drug eluting stents with biodegradable polymers, polymer-free DES, DES with novel coatings, dedicated bifurcation stents, and self-expanding stents in addition to more traditional bare-metal stents (BMS) and drug eluting stents (DES), which are often employed in modern treatment. The balloon expandable stents are made of a variety of materials, including cobalt-chromium alloy, nickel-titanium alloy, and medical grade stainless steel (316L).

3. **Response of Stent:**

Vascular stents are widely used for clinical purpose mainly in angioplasty to remove the blockages, [52]. There are tiny time and elongated term therapeutic effects on human body due to mechanical behaviour of coronary vascular stent [53, 54]. Therefore to improve the design of stent and its effective treatment on cardiac patient it is necessary to analysed mechanical properties of stent. After stent implantation, stent fracture is most important factor for serious complications (i.e. ISR) and it is clinically proved. Most of the stent fracture happened in the mid- late service time and few of them ruptured instantly after implantation [57]. It is observed that 78 % of serious stent fracture cases occurred in stent complication. According to statistical data [58] it is showed that, fthe stent restenosis rate increases from 3% to 15 % due to stent fracture. The restenosis rate before and after stent fracture [59] is different and it is 12.4% before stent fracture and 37.5 % after stent fracture.

4. Biomechanical properties of red blood cells:

The main function of RBC is to deliver oxygen [5] and eliminate carbon dioxide through lung gas exchange for tissue respiration. RBC typically lives 120 days, traveling 500 km through veins, arteries, and microscopic capillaries. RBC deformability is crucial for the transport of oxygen to tissues. The single and biconcave disk-shaped RBC, is having the measurements of roughly 8 µm in diameter and 2 µm in thickness. Spleen serves as a very efficient filter through which RBC pass. The cells must pass via incredibly small endothelial slits. Pathological variables cause splenic sequestration and RBC destruction when RBC deformability is reduced [2,13].

Three things are responsible for an RBC's deformability: (i) The enormous surface area to volume ratio of the biconcave disc, which has a mean cell volume (MCV) of 90 fl and a mean surface area (MSA) of 135 lm2, which is alarmingly higher than the surface area (97 lm2) of a sphere enclosing a volume of 90 fl;[22] (ii) the cytoplasmic viscosity, which is reduced by the presence of hemoglobin; (iii) the viscoelastic properties of the cell membrane, which is made up of three layers:

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an outer glycocalyx, which is rich in carbohydrates, an inner lipid bilayer that can resist bending, and an inner protein network that acts as the membrane skeleton and is in charge of the membrane's deformability, flexibility, and resilience. The RBC membrane's outside features a spherical shape that sends the cell membrane's malnourished veracity in a different direction. The latter, which may be assessed as surface roughness, is a sign of a cell's functional status changing [9,24] when it is ill or when there are external stimuli present, such as drugs[24,25,26].

4.1 Techniques for Measuring the Biomechanical Properties of RBCs:

There are a number of techniques for measuring the characteristics of RBCs, however the majority of researchers are continually challenged by the requirement to create models that mimic blood circulation under physiological settings. The developed experimental approaches can be broken down into two groups: single-cell techniques and equipment that measure whole blood or diluted RBC suspensions. Micropipette aspiration, optical tweezers, flickering analysis, AFM, microfluidics, and ultrasounds are a few single-cell experimental techniques.

5. Polymers for coating of stent:

Natural or manufactured materials that are initially biodegradable are contaminated in vivo either through enzymatic or non-enzymatic means, or both, to produce toxicologically safe and biocompatible by-products that are then eliminated through regular metabolic pathways. Over the past ten years, the use of such products for controlled medication delivery has dramatically expanded. The biomaterials utilized for medication delivery in cardiac patients fall into one of two categories: (1) synthetic biodegradable polymers, which include rather hydrophobic substances like hydroxy acids (a family that includes poly lactic-co-glycolic acid, or PLGA), polyanhydrides, and others. the naturally occurring polymers, including inorganics (hydroxyapatite) and complex carbohydrates (hyaluronan, chitosan) [44–46].

DES are typically coated with long-lasting polymers that allow for drug release and persist long after drug elution is finished. These persistent polymers have the potential to result in ST by impairing stent strut endothelialization, delaying healing, and triggering an allergic reaction [35]. Implants and other medical devices have traditionally been made of synthetic polymers, such as poly(ethylene) (PE), polyurethanes (PUR), poly(glycolide), and polylactides (PLA). PGA is frequently utilized as suture material for various surgical purposes, whereas PURs are well established as scaffold materials for vascular grafts due to their exceptional hemocompatibility. For PGA-based drug delivery systems, PGA-containing scaffolds combined with poly(-caprolactone) (PCL) are employed. Because PLA has a long history of being in vivo biocompatible, it has undergone extensive testing as a temporary stent material in cardiology [18]. The variety of diseases, dosing options, and potential unique requirements give rise to the wide range of materials utilized in drug administration. The biological milieu and the acceptability of particular drug-polymer-tissue interactions affect biocompatibility, which is not an inherent quality of a material [46]. Due to the lesser disparity between the characteristics of the polymers and the vascular tissue, polymeric stents often place less strain on the arterial system. There is a

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significant knowledge gap in the research of the mechanical behavior of polymer stents with various drug-eluting stent designs.

5.1 Poly lactic-co-glycolic acid (PLGA) Polymer:

The production of the drug coating on the stent surface blocks the transition proliferation of smooth muscle cells through drug sustained release, and is an effective technique for the treatment of restenosis [5-8]. Because of its dependable safety, outstanding biocompatibility, and manageable biodegradability, poly lactic-co-glycolic acid (PLGA) has demonstrated broad utility as a drug carrier.

It is easily biodegradable and works well as a carrier for drug-eluting stents. Typically, rapamycin and paclitaxel are the two major pharmacological stents used in clinical settings. Due to its broad safe dose range, specific suppression of cell proliferation, decrease in the production of local vascular cytokines, and inhibition of inflammatory cell activation, rapamycin (RAPA) has emerged as one of the most effective medications against stent restenosis [9,10].

For the past 20 years, polylactic-co-glycolic acid (PLGA) has been one of the most alluring polymeric possibilities utilized to create devices for tissue engineering and drug administration. In addition to having a wide variety of erosion times, customizable mechanical properties, and most significantly, being an FDA-approved polymer, PLGA is also biocompatible and biodegradable. Particularly, PLGA has received a great deal of attention in the creation of tools for the regulated administration of proteins, small molecule medicines, and other macromolecules in both commercial and academic settings [26].

6. Methods of coating of Polymer on stent:

Presently, coatings of polymer on the surfaces of vascular stents are formed by dip coating, but this process has many drawbacks, including winding, blockage, and non-uniformity [11,12]. To overcome these problems and to create homogeneous and smooth coatings, electrostatic spray deposition (ESD) techniques is used. In this case the polymer solution breaks down into tiny droplets that adhere to the substrate surface under the impact of a strong electric field. This technique is widely used in the manufacturing of machinery, the chemical industry, electronic information, micro medical devices, and healthcare [13–15].

Conclusion:

This review focuses on caidiovascular dieses and preventation of its therapeutic effects on human body due to behaviour of coronary vascular stent. The expandable balloon stent available in different material for exapansion of artery to proper flow of blood. To avoid the side effect like thrombosis, late restonesis due to stent, polymer coated drug eluted stent is used. Polymer plays important role at the time of stenting. It release the drug on right position and fixed the stent at the place where blockages are found. The polymers are coated on drug with the help of dip coating but due to drawback with this process, electrostatic spray deposition is adopted by the researhers.

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References:

1) Seung Hyuk Im, Dam Hyeok Im, Su Jeong Park, Youngmee Jung, Dong-Hwee Kim, Soo Hyun Kim, "Current status and future direction of metallic and polymeric materials for advanced vascular stents", Progress in Materials Science, pg. 126, 2022.
2) "Anatomy and Physiology of the Cardiovascular System." [Online]. Available: http://samples.jbpub.com/9781449652609/99069_ch05_6101.pdf. [Accessed: 19-Jan-2018].
3) Fred erique Etave, Gerard Finet, Maurice Boivina, Jean-Claude Boyera, Gilles Rioufol, Gilbert Thollet, "Mechanical properties of coronary stents determined by using finite element analysis", Journal of Biomechanics, page no. 1065–1075, 2001.
4) Jiang Xu, Jie Yang, Nan Huang, Christopher Uhl, Yihua Zhou, and Yaling Liu, " Mechanical response of cardiovascular stents under vascular dynamic bending", BioMedical Engineering, 2014.
5) Giovanna Tomaiuoloa, "Biomechanical properties of red blood cells in health and disease towards microfluidics", BIOMICROFLUIDICS, 2014.
6) Jun-kyu Park, Dong-Gon Kim, In Ho Bae, Kyung Seob Lim, Myung Ho Jeong, "Blood-Compatible and Biodegradable Polymer-Coated Drug-Eluting Stent", Macromolecular Research, Vol. 23, No. 3, pp 237-244, 2015.
7) Ziga Donik, Branko Neˇcemer, Matej Vesenjak, Sreˇcko Glodež and Janez Kramberger, "Computational Analysis of Mechanical Performance for Composite Polymer Biodegradable Stents", 2021.
8) Michelina Catauro, Elisabetta Tranquillo, Giovanni Dal Poggetto, Silvio Naviglio,and Federico Barrino, '"Antibacterial Properties of Sol–Gel Biomaterials with Different Percentages of PEG or PCL", Macromol. Symp. 2020.
9) Olga A. Sindeeva, Ekaterina S. Prikhozhdenko, Igor Schurov, Nikolay Sedykh, Sergey Goriainov, "Patterned Drug-Eluting Coatings for Tracheal Stents Based on PLA, PLGA, and PCL for the Granulation Formation Reduction:In Vivo Studies", 2021.
10) Sarah Barns, Marie Anne Balanant, Emilie Sauret, Robert Flower, Suvash Saha and YuanTong Gu, "Investigation of red blood cell mechanical properties using AFM indentation and coarse-grained particle method", BioMedical Engineering, 2017.
11) R. Ross, "Atherosclerosis — An Inflammatory D Isease," N. Engl. J. Med., vol. 340, no. 2, pp. 115–126, 1999.
12) E. Falk, "Pathogenesis of Atherosclerosis," J. Am. Coll. Cardiol., vol. 47, no. 8, pp. 0–5, 2006.
13) J. Ferrières, "A paradigm shift in the treatment of," Arch. Cardiovasc. Dis., vol. 108, no. 6–7, pp. 337–339, 2015.

DOI: 10.105515/JBE.40.3.27

14) R. J. Esper, R. A. Nordaby, J. O. Vilariño, A. Paragano, J. L. Cacharrón, and R. A. Machado, "Endothelial dysfunction : a comprehensive appraisal," Cardiovascular
15) Am. J. Pathol, "Intimal Thickening", Diabetology, vol. 18, pp. 1–18, 2006., vol. 89, p.:13-34, 1977.
16) P. Dutta, "Myocardial infarction accelerates atherosclerosis," Nature, vol. 487, pp. 325–329, 2012.
17) "Atherosclerosis."[Online]. Available: https://www.nhlbi.nih.gov/health-topics/atherosclerosis. [Accessed: 19-Jan-2018].
18) Anne Strohbach, and Raila Busch, "Polymers for Cardiovascular Stent Coatings", International Journal of Polymer Science, Volume 2015, Article 11 pages.
19) C. D. Mathers, T. Boerma, and D. Ma Fat, "Global and regional causes of death," Br. Med. Bull., vol. 92, no. 1, pp. 7–32, 2009.
20) D. Prabhakaran and P. Jeemon, "Global Burden of Cardiovascular Disease Cardiovascular Diseases in India," Circulation, pp. 1605–1620, 2016.
21) "Coronary Artery By-pass Grafting (CABG)." [Online]. Available: http://www.medanta.org/coronary-artery-by-pass-grafting-cabg/. [Accessed: 19-Jan-2018].
22) A. Iribarne et al., "The golden age of minimally invasive cardiothoracic surgery: current and future perspectives," Futur. Cardiol, vol. 7, no. 3, pp. 333–346, 2012.
23) R. N. Oda and K. S. Himamoto, "Long-Term Outcome After Primary Stenting Versus Balloon Angioplasty for Acute Myocardial Infarction Five-year Follow-up of a Case-control Study," Int Hear. J, vol. Vol 47, no. 1, pp. 47–57, 2005.
24) S. Garg and P. W. Serruys, "Coronary stents: Current status," J. Am. Coll. Cardiol., vol. 56, no. 10 SUPPL., pp. S1–S42, 2010.
25) S. Ramakrishnan, S. Mishra, R. Chakraborty, K. Sarat Chandra, and H. M. Mardikar, "The report on the Indian coronary intervention data for the year 2011 e National Interventional Council," Indian Heart J., vol. 65, no. 5, pp. 518–521, 2013.
26) Ziyang Jia, Chunyang Ma and Hongbin Zhang, "PLGA Coatings and PLGA Drug-Loading Coatings for Cardiac Stent Samples: Degradation Characteristics and Blood Compatibility", MDPI, 2021.
27) Catauro, M.; Tranquillo, E.; Dal Poggetto, G.; Naviglio, S.; Barrino, F. Antibacterial properties of sol-gel biomaterials with different percentages of PEG or PCL. Macromol. Symp., 389, 2020
28) Sofogianni, A. Lipoprotein-associated Phospholipase A2 and Coronary Heart Disease. Curr. Pharm. Design., 24, 163–168. [CrossRef] [PubMed], 2018.
29) Zheng, Q.L.; Qiao, X.; Ren, S.F.; Zhao, Z.P. Effect of severe stenosis or occlusion of small vessel on coronary artery after cardiac stent implantation on cardiac function. Clin. Res. Pract., 13, 131–137, 2018.

DOI: 10.105515/JBE.40.3.27

30) Mostaed, E.; Sikora, J.; Malgorzata, D.; Jaroslaw,W. Zinc-based alloys for degradable vascular stent applications. Acta Biomater, 71, 1–23. [CrossRef]. 2018.
31) Katayama, Y.; Kubo, T.; Akasaka, T.; Aoki, H. TCTAP A-085 Vascular Response to Drug-eluting Stent with Biodegradable Versus Durable Polymer. J. Am. Coll. Cardiol, 13, S47. [CrossRef],2017.
32) Francesca, B.M.; Francesco, B.; Carlo, T.; Ornella, L. Coronary stents and vascular response to implantation: Literature review. Pragmat. Obs. Res., 8, 137, 2017.
33) Chalony, C.; Aguilar, L.E.; Chan, H.P. Drug free anti-cell proliferative and anti-platelet adhesion coatings for vascular stents via polymeric electrospun fibers. Mater. Lett. 291, 1295–1302. [CrossRef], 2021.
34) Wu, T.; Chen, X.; Fan, D.Z.; Pang, X.L. Development and application of metalmaterials in terms of vascular stents. Bio-Med. Mater. Eng. 25, 628–635, 2015.
35) Liang, C.; Hao, J.; Wang, H.; Li, B.; Xia, D. Preparation and Research Progress of Contact-Induced Surface of Metal Implants. Acta Metall Sin, 13, 21–28, 2017.
36) Togha, M.; Jahanshahi, M.; Alizadeh, L.; Jahromi, S.R.; Ghaemi, A. Rapamycin Augments Immunomodulatory Properties of Bone Marrow-Derived Mesenchymal Stem Cells in Experimental Autoimmune Encephalomyelitis. Mol. Neurobiol. 2017, 54, 2445–2457. [CrossRef] [PubMed], 2017.
37) Gu, C.F.; Fu, Q.Y.; Liu, J.; Cardiology, D.O. Advances in Coronary Drug-eluting Stent Restenosis. Adv. Cardiovasc. Dis, 371, 968–974, 2017.
38) Hilliard, S.; Baldinozzi, G.; Friedrich, D.; Kressman, S.; Strub, H.; Artero, V. Mesoporous thin film WO3 photoanode for photoelectrochemical water splitting: A sol-gel dip coating approach. Sustain. Energy Fuels, 1, 145–153. [CrossRef], 2017.
39) Bakhsheshi-Rad, R.H.; Hamzah, E.; George, J.; Safaa, D.; Saud, N. Fabrication and characterisation of novel ZnO/MWCNT duplex coatings deposited on Mg alloy by PVD coupled with dip-coatings techniques. J. Alloys Compd., 728, 4478–4486. [CrossRef], 2017.
40) Xia, F.; Li, C.; Ma, C.; Li, Q.; Xing, H. “Effect of pulse current density on microstructure and wear property of Ni-TiN nanocoatings deposited via pulse electrodeposition”, Appl. Surf. Sci., 538, 148139. [CrossRef], 2021.
41) Ma, C.; Zhao, D.; Ma, Z., “Effects of duty cycle and pulse frequency on microstructures and properties of electrodeposited Ni-Co-SiC nanocoatings”, Ceram. Int., 46, 12128–12137. [CrossRef], 2020.
42) Xia, F.; Li, Q.; Ma, C.; Liu,W.; Ma, Z. “Preparation and wear properties of Ni/TiN-SiC nanocoatingss obtained by pulse current electrodeposition”, Ceram. Int., 46, 7961–7969. [CrossRef], 2020.
43) Sidewinder, O.A.; Prikhozhdenko, E.S.; Schurov, I. “Patterned Drug-Eluting coatingss for Tracheal Stents Based on PLA, PLGA, and PCL for the Granulation Formation Reduction: In Vivo Studies”, Pharmaceutics 2021, 13, 119–126.

DOI: 10.105515/JBE.40.3.27

44) Qi, H.; Heise, S.; Zhou, J.; Schuhladen, K.; Lu, T. "Electrophoretic Deposition of Bioadaptive Drug Delivery coatingss on Magnesium Alloy for Bone Repair", Acs. Appl. Mater. Interfaces 2019, 11, 35–42. [CrossRef].
45) Uhrich, K.E.; Cannizzaro, S.M.; Langer, R.S.; Shakesheff, K.M. "Polymeric systems for controlled drug release", Chem. Rev. 1999, 99, 3181–3198..
46) Nair, L.S.; Laurencin, C.T. Biodegradable polymers as biomaterials. Prog. Polym. Sci. 2007, 32, 762–798.
47) Anderson, J.M.; Shive, M.S. "Biodegradation and biocompatibility of PLA and PLGA microspheres", Adv. Drug Deliv. Rev. 1997, 28, 5–24.
48) Scot Garg, MB, CHB, Patrick W. Serruys, "Coronary Stents", Journal of the American College of Cardiology, Elsevier, Vol. 56, No. 10, ISSN 0735-1097,2010.
49) Gregory Katz & Bhisham Harchandani & Binita Shaha, "Drug-Eluting Stents: the Past, Present, and Future", Springer Science Business Media New York, 2015.
50) Hirenkumar K. Makadia and Steven J. Siegel, "Poly Lactic-co-Glycolic Acid (PLGA) as Biodegradable Controlled Drug Delivery Carrier", Polymers, ISSN 2073-4360,pp 1377-1397, 2011.
51) Ida Dulin´ska a,b, Marta Targosz, Wojciech Strojny, Maygorzata Lekka, Pawey Czuba, Walentyna Balwierz, Marek Szymon´ski, "Stiffness of normal and pathological erythrocytes studied by means of atomic force microscopy", biochemical and biophysical methods, 2005.
52) Cheng-Chang Liena, Meng-Chien Wub, Chyung Ay, "Study on the Young's Modulus of Red Blood Cells using Atomic Force Microscope", Applied Mechanics and Materials Vol. 627 (2014) pp 197-201, 2014.
53) Garg S, Serruys PW. "Coronary Stents: current status", J Am Coll Cardiol, ;56(10 Supplement):S1–42. Xu et al. BioMed Eng OnLine (2016) 15:21 Page 19 of 20, 2010.
54) Sangiorgi G, Melzi G, Agostoni P, Cola C, Clementi F, Romitelli P, Virmani R, Colombo A, "Engineering aspects of stents design and their translation into clinical practice" Ann Ist Super Sanita,43(1):89–100, 20017.
55) Katz G, Harchandani B, Shah B. "Drug-eluting stents: the past, present, and future", Curr Atheroscler Rep.17(3):485, 2015.
56) Etave F, Finet G, Boivin M, Boyer J-C, Rioufol G, Thollet G. Mechanical properties of coronary stents determined by using finite element analysis. J Biomech, 34(8):1065–75, 2001.
57) Migliavacca F, Petrini L, Colombo M, Auricchio F, Pietrabissa R. "Mechanical behavior of coronary stents investigated through the finite element method", J Biomech, 35(6):803–11, 2002.
58) Nakazawa G, Finn AV, Vorpahl M, Ladich E, Kutys R, Balazs I, Kolodgie FD, Virmani R. "Incidence and predictors of drugeluting stent fracture in human coronary artery: a pathologic analysis", J Am Coll Cardiol, 54(21):1924–3, 2009.

DOI: 10.105515/JBE.40.3.27

59) Umeda H, Gochi T, Iwase M, Izawa H, Shimizu T, Ishiki R, Inagaki H, Toyama J, Yokota M, Murohara T. Frequency, "predictors and outcome of stent fracture after sirolimus-eluting stent implantation", Int J Cardiol, 133(3):321–6, 2009.
60) Aoki J, Nakazawa G, Tanabe K, Hoye A, Yamamoto H, Nakayama T, Onuma Y, Higashikuni Y, Otsuki S, Yagishita A, "Incidence and clinical impact of coronary stent fracture after sirolimus-eluting stent implantation", Catheter Cardiovasc Interv, 69(3):380–6, 2007.
61) Lee S-H, Park J-S, Shin D-G, Kim Y-J, Hong G-R, Kim W, Shim B-S. "Frequency of stent fracture as a cause of coronary restenosis after sirolimus-eluting stent implantation",Am J Cardiol,100(4):627–30, 2007.

DOI: 10.105515/JBE.40.3.27