Asian Journal of Pharmaceutical and Clinical Research

INNOVARE ACADEMIC SCIENCES
Knowledge to Innovation

Vol 11, Issue 5, 2018

Online - 2455-3891
Print - 0974-2441

Review Article

POLYMERS IN CARDIOVASCULAR SURGERY

RAMI MATARNEH[1]*, SVITLANA SOTNIK[2], VYACHESLAV LYASHENKO[3]

[1]Department of Computer Science, Prince Sattam Bin Abdulaziz University, Al-Kharj, Saudi Arabia. [2]Department of Computer-Integrated Technologies, Automation and Mechatronics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. [3]Department of Informatics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine. Email: ramimatarneh@gmail.com

Received: 05 January 2018, Revised and Accepted: 24 January 2018

ABSTRACT

Surgical intervention is still one of the most important treatment methods to investigate or treat a pathological condition, and the cardiovascular surgery is considered one of the most important types of surgical interventions at all. The uniqueness of a human body and the impossibility of its full procreation, enforces the use of various auxiliary materials such as polymers to carry out the most difficult surgery while ensuring further vital activity. In this paper, we explore the features of polymers which are used in cardiovascular surgery, discussing the existing variety of such polymers and the orientations of their use. Depending on the carried out analysis, the classification of main types of polymers had been offered which are the most suitable for cardiovascular surgery, besides generalized classification of polymeric products defects. The obtained results enable to immediately identify all significant factors that may lead to emergence defect for the purpose of its control and prevention to improve the quality of surgical intervention and stabilize the patient's cardiovascular system.

Keywords: Polymers, Cardiovascular surgery, Blood vessels, Prosthesis, Heart, Catheter.

 DOI: http://dx.doi.org/10.22159/ajpcr.2018.v11i5.24576

INTRODUCTION

The cardiovascular system (blood circulatory system) provides all the vital functions of organism [1,2]. The main components of cardiovascular system: Blood, blood vessels, and heart and their compounded functioning deliver oxygen and all other necessary nutrients to tissues, get rid of the liquid wastes, control of all numerous functions through endocrine system, and a thermoregulation [3,4]. At the same time, the congenital heart disease (CHD) is one of the most common abnormal forms (a peculiar defect) inherent in a human body [5,6].

In the course of CHD treatment, health workers can face a set of various complications. For example, certain problems can be caused of anatomic differences of patients. The appropriate design and adaptation of the grafts which will allow to correct this defect are not less important and are bounded to its orientation, material, and form which considered as an integral part for the achievement of successful surgical results [6,7]. At the same time, the current grafts used in the corresponding procedures are suffer from progressive obstruction, infection, durability, and a possibility of hardening.

Nevertheless, the use of polymers in cardiovascular surgery is the integral component for convalescence achievement of the patient, as the polymers have high-molecular bonds with a very high possibility of unlimited modification and practically not, which is explain their successful use [6]. The high chemical inactivity of polymers corresponds to high biological inactivity [7].

Typically, the general issues of cardiovascular surgery include problems of anesthesiology, resuscitation, cardiopulmonary bypass, computerization, use of polymeric and biological materials, and a number of other questions for the methodological purpose [5].

When considering the application of polymers in cardiovascular surgery, first of all, it should be noted the purpose of usage and the tissue of the patient. Previously, the explants were the parts of vessels taken from the patient (autoosta) [7]; however, the possibility of their use was very limited. However, the possibility of their use was very limited. Therefore for solving the problem began to consider the design of artificial material. The results of the polymeric prostheses use have yielded the positive results [8,9].The key to this aspect is the reaction to the foreign body which may lead to rejection or isolation in a form of encapsulation [10] manifests itself as thrombotic masses [4,5,9]. However, there are a number of factors that contribute to prevent the vessel lumen to limit the growth of such thrombotic masses: First, it is established that the function of the prosthesis in the vast majority of cases persists in the prosthetics of the aorta and its major branches [10-14] due to the favorable conditions of high blood flow.

Second, the function of prosthesis is promoted by the safety of distal vessels prosthesis and also using drugs to reduce the general coagulability of a blood. Therefore, it was determined that the choice of synthetic fibers is an important factor in performing vascular surgery [8,14]. At the same time, it has also been shown that, despite the high biological inactivity, there are different groups of polymeric fibers that vary in degree of inertia [14]. Therefore, three major fiber groups were identified: Polyamide, polyester, and polytetrafluoroethylene. However, long-term functioning of the prosthesis takes place only at the prostheses of the aorta and its major branches.

As leading pathology is a cardiovascular disease, the largest set of medical prescription are represented for cardiovascular materials [2,5,14], and the task of analyzing polymers and its classification of usage should be considered very relevant.

VARIETY OF POLYMERS IN CARDIOVASCULAR SURGERY

The most developed direction in cardiovascular surgery using new biomaterials and devices is the heart surgery. At the same time, materials for cardiovascular surgery represent the most larger group of the medical prescription of the applied materials. The most perspective and widely used materials are polymers. The scope of polymers begins with storage spaces for blood, needles, and syringes and ends with intravascular catheters, prostheses of blood vessels, artificial valves of the heart, the systems of an artificial, and artificial circulatory support (Table 1) [1-8].

Hence, all polymers which are used in cardiovascular surgery can be classified as biostable, biodegraded, and materials from natural polymers. This means that all given products from polymers for cardiovascular surgery (PCVS) must be resurveyed depending on this classification.

Biostable synthetic polymers: These polymers are not hydrolyzed in liquid mediums, not blasted under the blood and tissue enzyme influence or under the influence of cells and are intended for production of implants and devices of long functioning, among them - polyethylene, polypropylene, polyethylene terephthalate, nylon, polytetrafluoroethylene, and polymethyl methacrylates [5,7].

Biodegradable polymer materials are spontaneously collapsing as a result of natural microbiological and chemical processes [6-8].

The materials from natural polymers, in general, combine a large number of various composition and properties of plant and animal origin [1,7,8]. The most common strategy for dealing with the critical problems of the cardiovascular system and heart disease is the application of the artificial heart valve (AHV) and the artificial blood vessel (ABV) and in the installation of devices to stimulate the heart, in particular pumps and pacemakers [2]. Analysis of the application of polymers to AHV shows that one of the major problems associated with biological substances that contact blood is the compatibility of those substances with blood. The most commonly used biological materials are proteins of human origin such as heparin, fibronectin, collagen, and vitronectin which can improve the cohesion of the behavior of endothelial cells [5,14].

Table 1: PCVS and some of their areas

Type of material	Material name
Heart valves and elements of the artificial heart	
Biostable synthetic polymers	Polyimides Polyethylene Polysulfone Polycarbonate Epoxysilane Polyurethanes
Plate, which is attached to the heart valves	
Biostable synthetic polymers	Polytetrafluoroethylene (Teflon)
Catheters and their coated	
Biostable synthetic polymers	Polyvinilchloride Fluorocarbon
Framework for vessels (stents)	
Biostable synthetic polymers	Polyurethane Silicons PET
Framework for vessels (stents)	
Biodegraded polymers	Polylactide Polyurethane Polycaprolactone Polyorthoaethers
Coverings controlled release	
Materials from natural polymers	Chitosan
Structural materials for extracorporeal devices	
Biostable synthetic polymers	Acrylates Polycarbonates
Biodegraded polymers	Polyanhydride Polyhydroxyalkanoate Polycaprolactone Copolymers lactitol and glycolide
Vascular grafts and ABVs	
Biostable synthetic polymers	Polytetrafluoroethylene (Teflon) Polyester (PE) fiber Polyamides
Biodegraded polymers	Polycaprolactone Polyhydroxybutyrate with oxovalerate (PHBV)
Coverings for vascular prostheses	
Materials from natural polymers	Sewed albumin
Membranes	
Biostable synthetic polymers	PET
Biodegraded polymers	Polioksialkanoata
Membranes for a hemodialysis	
Materials from natural polymers	Acetate and cellulose hydrate

PCVS: Polymers for cardiovascular surgery, ABVs: Artificial blood vessels, PET: Polyethylene terephthalate

In particular, polymeric materials are the best alternative in compensation and replacement of heart valves (Fig. 1), but they are not functionally efficient compared to biological tissues.

To group, the main types of polymers, including synthetic polymers biostable, which are used for AHVs, will be as follows: Polyimides, polysulfone, and epoxysilane [4,14].

Cardiac catheter (Fig. 2) was originally used for measuring the pressure in the beating heart. During catheter examination, if there is narrowing (stenosis) or deposits on the vessel walls, a balloon catheter or implant frame must be inserted for vessels (stent). Nowadays, the catheter is used for ablation and cryoablation. As catheters are used in polyurethanes and polyvinyl chlorides [4,5].

Another area of polymers' application is the gradual substitution of the implanted bioresorbable scaffold for vascular (stent) of the normal

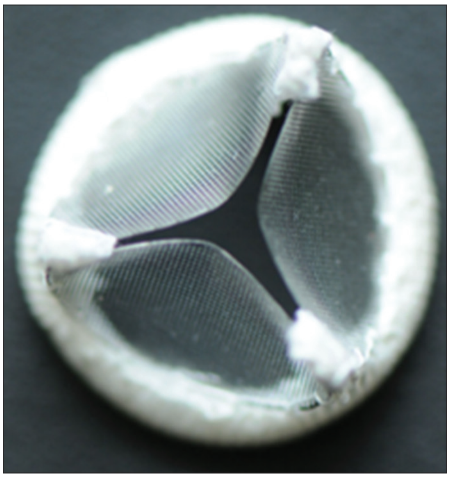

Fig. 1: Hybrid valve from polymer

Fig. 2: Appearance of coronary stents and balloon catheters

vascular tissue. Although this innovative direction opened up prospects for radical solutions to the problem, it still surrounded by many uncertainties.

There are also isolated examples of the stents made of completely destructible materials (polylactides, polyurethanes, and silicone) [15].

The medical device, such as stent and synthetic graft, is covered with the pharmaceutical composition consisting of a matrix with controlled release of one or several pharmaceutical substances where these materials usually serve materials from natural polymers (Table 1).

Both the synthetic biostable and biodegraded polymers are applied as constructional materials to extracorporeal devices [14,15].

The most important aspect of polymers usage is their use in monolithic tubes (vascular prostheses) or ABVs (Fig. 3) [5,14,16]. The prostheses of blood vessels which are made from artificial materials (ABVs) are applied to replace the defective blood channel or to create collateral routs in the blood circulatory system. The artificial prostheses of blood vessels applied in heart surgery are very various also among them: The biodegraded prostheses from the bioresorbable polymers, prostheses from composite materials, and hybrid prostheses from synthetic materials with biological coverings (fibrin or collagen) or the sowed cells (tissue-engineered prostheses of vessels) [2].

The prosthesis of the biodegradable material is a graft from natural polymers which are synthesized by bacteria. The polymer (polyhydroxybutyrate, polyalkanoates, etc.) is degradable after a certain time when incorporated into the human body and exposed to proteolytic enzymes. This, in essence, creates a frame (skeleton) of the polymer, which, in turn, consists of biologically active factors and growth factors, which attract cells of the predecessor of normal cells in the blood (cells normally circulate in the blood) [1,9,13,14]. The high hemocompatibility is the main requirement of the materials and the implants of the blood vessels [9].

However, the most difficult task is to build vascular prostheses with a small diameter depending on applied techniques such as lotions, dense, porous, knitted, braided, and woven, and the most common technique is the knitted construction which is characterized by a high elasticity and flexibility [11-15].

Metals were the first materials that were tried to use for the construction of ABVs. The most successful development of that period as developed in the United States implants of blood vessels in the form of knitted tubing was made from polyethylene terephthalate (PET) brand "Dakron" [9].

Fig. 3: Appearance of artificial blood vessels from biodegradable polymer

The use of porous and foam-polymeric materials allowed to make continuous (not goffered) porous by reinforcing rises in the places of flexures rings or grid (Fig. 4).

The most widely used in clinical practice are vascular prostheses on the basis of PET [16,17]. It is the most chemically stable and biologically inert polymer material, so that the implantation of prostheses accompanied by a minimal reaction to surrounding tissue. In this case, the material for a long time under the influence of biological environments *in vivo* does not alter their biomedical and physicochemical properties.

Polymers were widely used in membranes [5,6] on the basis of the biodegraded natural polymers to effectively bond wounded surfaces without any toxic formations, i.e., hemodialysis membranes.

Polymers are also used as filling compounds to fill aneurysms (bloating) because the composition of the α-cyanacrylate acid esters hardens in the presence of moisture. There are isolated examples of the polymer materials use, in particular, polyhydroxybutyrate as emboli (plugs) for blockage of vessels [17].

In open-heart surgery with surgical damage, there is a need to use an artificial implant ("patches"); otherwise, there will be complications with adhesion [18,19].

Polymeric materials are also widely used in various designs of auxiliary blood circulation devices. Methods of circulatory support the most widely used intra-aortic pump balloon veins-arterial perfusion, mechanical cardiomasseur (assistor of the heart), and artificial heart ventricle [18-21]. Application of circulatory support methods is often accompanied by thrombosis and thromboresistant. One of the thrombosis reasons is that these designs tend to use large contact area between the blood and the polymer surfaces. Polymeric materials such as polyethylene, fluoropolymer, polyurethane, acotan (kremiyorganic rubber+polyurethane), and biomeasures are all can be used in manufacturing of nutritionally pumpscans [18]

BASIC PROPERTIES AND DEFECTS OF POLYMER PRODUCTS IN CARDIOVASCULAR SURGERY

To avoid defects of polymer products in cardiovascular surgery, materials must have certain properties. Table 2 shows the most commonly used materials with basic properties that must be clearly observed [12-14], to avoid any potential irreversible results for the patient.

Characteristics of polymers used as cardiovascular biomaterials and their influence on the organism are presented in Table 3 [18,20].

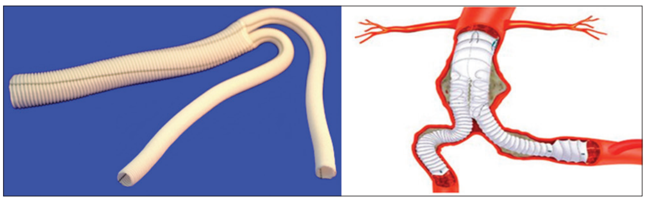

Fig. 4: The prosthetic blood vessel of polytetrafluoroethylene

Table 2: Properties of polymers used as cardiovascular biomaterials

Properties	Polyamides	Polyolefin	Polyester	Polytetrafluoroethylene	Polyurethanes
Strength	Medium	Good	Good	High	Better
Hardness	Medium	High	High	High	Medium
Rigidity	Medium	High	High	High	Medium
Blood compatibility	Good	Better	Moderate	Low	Good

THE ACHIEVEMENT OF QUALITY PLASTIC PRODUCTS IN CARDIOVASCULAR SURGERY

The successful use of polymer in cardiovascular surgery can only be achieved through a clear methodology to detect and prevent defects. Table 4 summarizes major defects, problems and solutions to polymers.

The most important, in addition to material selection, is the rational mode of processing method. Allowable temperature processing of polymeric materials in the manufacture of medical devices is summarized and shown in Table 5 [14,20-25].

The ever-increasing demands to improve the quality and increase the accuracy of polymer articles, can only be achieved through regulation and control by adopting strict conditions and a strong relationship between product quality indicators (eg, shape, dimensional accuracy and surface quality).In other words, the cause of the presence/occurrence of defects in polymers products for the needs of cardiovascular surgeons also needs to be considered from the viewpoint of manufacturing process. The control of such a process is advantageously carried out in accordance with the algorithm of quality assessment polymer products cardiovascular surgery (PPCS), which is shown in Fig. 5.

Table 3: Defects in polymers and their effect on the body

Made of polymers	Properties	Affects	The reason
Models of AHVs (ball, disk, and blade)	Mechanical surface finish AHVs should not be below 9–10th class	Blood clots	Surface treatment
1. Heart valve 2. Defects in the walls of blood vessels	1. Enhanced chemical resistance 2. Stability at operation that is not blasted, for example, the polydimethylsiloxane and polypropylene have the following values of a sorption of water and diffusion coefficients, respectively, 0.07 and 0.007 g H_2O/100 g of polymer and 70,000 and 240 cm^2 s^{-1}	1. Erosion, which consists in emergence of excavations of irregular shape 2. Can form pores, indentations, cracks 3. Defects in a look "uzur," cracks, and channels on sections of threads	The polymer has, in its structure, the group of hydrolyzable tannins, which are destroyed in biological fluids as a result of hydrolytic processes Biological hydrolysis of polymers occurs under the influence of blood and tissues enzymes, or enzymes, produced by cells
Cardiomessenger (assistor heart)	1. Rational size 2. High-performance polymer and its elastic properties, and the degree of thromboresistance	Thrombosis	1. A large area of contact with blood the polymer surfaces 2. Correctly selected polymer

AHVs: Artificial heart valve

Table 4: Main problems of the articles of polymers in cardiovascular surgery and their prevention

Problem	Reason	Prevention
Insufficient mechanical purity of a artificial valves heart surface	1. Material is incorrectly chosen 2. Violations surface treatment 3. Artificial damage to the ABVs surface	1. The use of polymers having thromboresistant properties 2. Control of surface treatment 3. Rational choice of surface treatment method of ABVs
Erosion-hollows of irregular shape Pores Cracks Deepening	1. A method of processing material in the product 2. The shape and weight of the prosthesis 3. The place of introduction into the body	1. Rational choice of the material into the product processing method 2. A rational choice of the insertion site prosthesis in the body 3. The correct choice of the shape and weight of the prosthesis

ABVs: Artificial blood vessels

Table 5: Allowable temperature processing of polymeric materials in the manufacture of polymer products for the cardiovascular surgery needs

Material name	Temperature °C degradation (initial)	Temperature °C processing (max.)	Method of forming
Polyamides	150	280	Spinning
Polyvinylchloride	150	160	Milling, welding
Polymethylmethacrylate	300	225	Welding
Polypropylene	280	260	Injection molding
Polyorganosiloxanes	260	210	Pressing
Polystyrene	250	205	Injection molding
Polytetrafluoroethylene	300	375	Sintering
Polyethylene	100	120	Rolling
		250	Injection molding

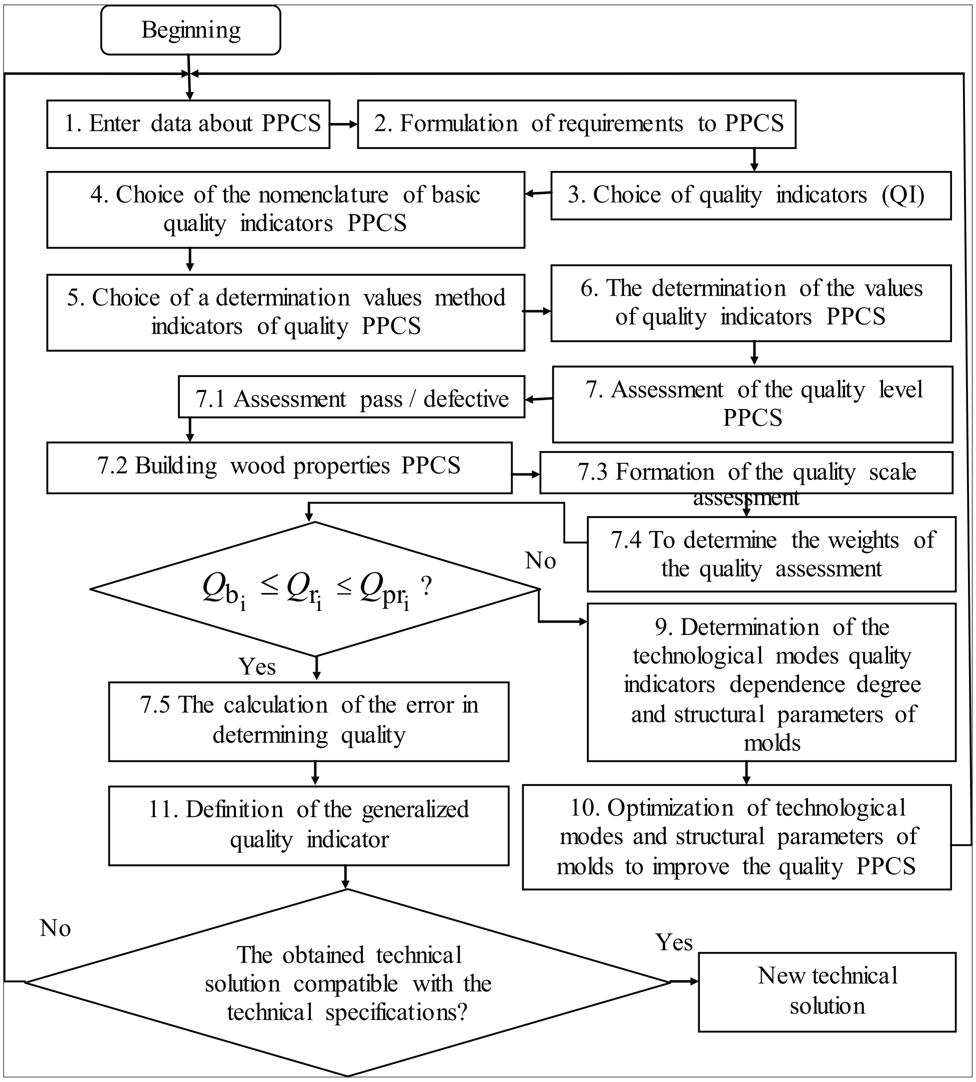

Fig. 5: A generalized algorithm for evaluating the quality polymer products cardiovascular surgery

Q_{r_i} - value of the ith quality score of the evaluated polymeric materials, which may vary in the range $[Q_{b_i}, Q_{pr_i}]$.

The highest quality of PPCS is possible by simultaneous optimization of technological regimens and constructional parameters of the corresponding polymeric forms [21,26].

In general, the offered methodology of the defects analysis and factors of their emergence for the achievement of PPCS quality allows to define all significant factors which immediately will influence the emergence of defect for the purpose of control and prevention, which in turn will lead to improve the quality and results of surgical intervention.

CONCLUSIONS

In this paper, a variety of polymers were explored and discussed with intensive analysis of their properties and uses in cardiovascular surgery.

The analysis of possible defects of polymers for needs of cardiovascular surgery has been carried out and shown that such defects can arise because of a regimen disturbances of polymers' shaping, non-compliance with regimens when processing a surface of such products, and incorrect choice of material. Based on the analysis of the underlying factors that may lead to defects, a general classification of the causes of these defects has been reviewed to provide high-quality polymer products that will contribute effectively to the success and stability of cardiovascular surgery and provided a general classification of the causes that may affect the defects of these polymers. these polymers, in addition to classifying and discussing the scope of application of the main polymers types that are most suitable for cardiovascular surgery.

The main characteristics of PCVS have been identified: High chemical inertness and elasticity, biocompatibility (hemocompatibility), thromboresistant, and stereoconfiguration. As a final conclusion, polymers are the right and most appropriate choice among other materials because of its distinctive features and characteristics.

CONFLICT OF INTERESTS

The authors declared that there was no conflict of interest.

REFERENCES

1. Yashiro B, Shoda M, Tomizawa Y, Manaka T, Hagiwara N. Long-term results of a cardiovascular implantable electronic device wrapped with an expanded polytetrafluoroethylene sheet. J Artif Organs 2012;15:244-9.
2. Arafat M. Approaches to achieve an oral controlled release drug delivery system using polymers: A recent review. Int J Pharm Pharm Sci 2015;7:16-21.
3. Salih OS, Nief RA. Effect of natural and synthetic polymers on the properties of candesartan cilexetil matrix tablet prepared by dry granulation. Asian J Pharm Clin Res 2016;9 Suppl 3:161-70.
4. Anepu S, Duppala L, Sundari MS. Formulation development,

characterization and *in-vitro* evaluation of floating matrix dosage form of tramadol hydrochloride using various polymers. Asian J Pharm Clin Res 2017;10:281-90.
5. Raz S. Atlas of Transvaginal Surgery. Philadelphia, PA: Lippincott-Raven; 2002.
6. Puoci F, editor. Advanced Polymers in medicine. Cham: Springer; 2015.
7. Syazana N, Sukmana I. Electrospun-based fibrous scaffold for cardiovascular engineering applications: A review. Arpn J Eng Appl Sci 2016;11:4778-81.
8. Bezuidenhout D, Williams DF, Zilla P. Polymeric heart valves for surgical implantation, catheter-based technologies and heart assist devices. Biomaterials 2015;36:6-25.
9. Jaganathan SK, Supriyanto E, Murugesan S, Balaji A, Asokan MK. Biomaterials in cardiovascular research: Applications and clinical implications. Biomed Res Int 2014;2014:459465.
10. Sakhare MS, Rajput HS. Polymer grafting and applications in pharmaceutical drug delivery systems - A brief review. Asian J Pharm Clin Res 2017;10:59-63.
11. Chukka S, Shaik S. Development and characterization of gastroretentive drug delivery system for ritonavir tablets using natural polymers. Asian J Pharm Clin Res 2017;10:318-22.
12. Jacob L, Tv A, Abraham S. Formulation and evaluation of perindopril microencapsules by using different polymer. Asian J Pharm Clin Res2017;10:153-6.
13. Singh S, Neelam, Arora S, Singla Y. An overview of multifaceted significance of Eudragit polymers in drug delivery systems. Asian J Pharm Clin Res 2015;8:1-6.
14. Manimaran V, Damodharan N. Development of fast-dissolving tablets of amlodipine besylate by solid dispersion technology using poloxamer 407 and poloxamer 188. Asian J Pharm Clin Res 2017;10:135-41.
15. Kheradvar A, Groves EM, Dasi LP, Alavi SH, Tranquillo R, Grande-Allen KJ, *et al.* Emerging trends in heart valve engineering: Part I. Solutions for future. Ann Biomed Eng 2015;43:833-43.
16. Scholz C. Polymers for Biomedicine: Synthesis, Characterization, and Applications. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 2017.
17. Ducheyne P, Healy K, Hutmacher DE, Grainger DW, Kirkpatrick CJ. Comprehensive Biomaterials. Newnes: Amsterdam; 2015.
18. Abbara S, Walker TG, Ng P. Diagnostic Imaging: Cardiovascular. Philadelphia, PA: Amirsys Lippincott Williams and Wilkins; 2008.
19. Jyosna D, Jyothi BJ. Multiparticulate drug delivery systems using natural polymers as release retardant materials. Int J Pharm Pharm Sci 2014;10:61-5.
20. Qi P, Maitz MF, Huang N. Surface modification of cardiovascular materials and implants. Surf Coat Technol 2015;233:80-90.
21. Bonaterra GA, Zügel S, Kinscherf R. Novel systemic cardiovascular disease biomarkers. Curr Mol Med 2010;10:180-205.
22. Patel MB, Shaikh F, Patel V, Surti NI. Controlled-release effervescent floating matrix tablets of metformin using combination of polymers. Int J Pharm Pharm Sci 2016;8:114-9.
23. Roifman I, Beck PL, Anderson TJ, Eisenberg MJ, Genest J. Chronic inflammatory diseases and cardiovascular risk: A systematic review. Can J Cardiol 2011;27:174-82.
24. Ruel M, Gardner TJ. Introduction to the 2017 cardiovascular surgery – Themed issue of circulation. Circulation 2017:1675-1675.
25. Nagam SP, Jyothi AN, Poojitha J, Aruna S, Nadendla RR. A comprehensive review on hydrogels. Int J Curr Pharm Res 2016;8:19-23.25.
26. Sotnik S, Matarneh R, Lyashenko V. System model tooling for injection molding. Int J Mech Eng Technol 2017;8:378-90.