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JSM Nanotechnology & Nanomedicine

Review Article

Future of Polymer Materials in Bio-science Applications

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Submitted: 16 June 2020
Accepted: 02 July 2020
Published: 04 July 2020
ISSN: 2334-1815

Keywords
- Polymer materials
- Drug delivery
- Therapeutic compounds
- Bio-medical devices

Abstract

Polymer materials have been playing an essential role in the advancement of drug delivery systems by serving as controlled, cyclic and tunable release of therapeutic compounds. Recent advancements in the functional materials enabling us to rationally engineer, tailor the polymer morphological characteristics with respect to the desired cargo and perform multiple biological functions. The flexibility of smart electro active polymers allowed the progression in bio-medical devices that can carry targeted polymer-drug conjugates for direct intercellular delivery. This review summarizes a general overview of few latest developments in the bio-compatible functional polymer materials and applications in topical, intravenous and carrier drug conjugates.

INTRODUCTION

Polymer based drug delivery systems (DDS) are gaining utmost attention due to their topical application on the diseased tissues, wounds/cuts and muscle regeneration. The true intent of these polymer carrier systems lies in the of pain mitigation and intermittent dosage application of intravenous injections [1,2]. Using polymer-based DDS precisely controlled dosage of drugs can be given to the patients over a long period of time (from anywhere between 16 to 48 hours). Some applications of polymer-based DDS are topical wound healing, skin allergies and as anesthetics [3]. Polymers have carbon chains with reactive C, H, F, O, Cl., etc. atoms/molecules and can accommodate other advantageous functional molecules with several therapeutic medicinal advantages [4].

Structural diversity, flexibility and ease of machining of polymeric materials interests them for several other application in many industries like filtration & separation, catalysis, protective clothing, automobile, piping and housing, insulations and many more [5,6]. The usage of micron/sub-micron-sized synthetic, natural and composite polymer fibers in filtration and separations industry is raising at an alarming rate due to higher particle retention efficiencies compared to fiber media with relatively larger diameters. Electrospinning, force-spinning, melt-blowing are some of the most versatile and capable of fabricating continuous long single fibers with a cross sectional fiber diameters ranging from a few nanometers to several microns [4,7,8]. Slender 3-dimentional polymeric fiber membranes gained commercial and scientific attention due to their high surface to volume ratio and well-defined internal pore geometry for most advanced targeted area drug delivery [9,10]. The key functions of these bio-degradable implantable polymeric medical devices include bio-compatibility, longevity, structural integrity and stability [11-14].

ELECTROACTIVE POLYMERS FOR DRUG DELIVERY

The most profoundly used carriers for polymer therapeutics are HPMA (polymer-drug) and PEG (polymer-protein), but other systems studied includes chitosans, poly (glutamic acid), dextran, poly (aspartamides) and poly (L-lysine) as polymeric carriers. Polymer-drug and polymer-protein conjugates typically studied have a tripartite structure: polymer, linker, and therapeutic agent. However, more complex systems now exist that incorporate additional features for targeted delivery or combination therapies [15,16]. Other applications for polymer materials also include heart valve replacement, artificial blood vessels are made of medical grade synthetic polymeric materials like Teflon, Dacron and poly urethane etc., [1,3].

Jindal et al. [17], reported the complete encapsulation of anti-inflammatory drug, Zafirlukast, into the electrospun fibers made from polyisobutylene-based thermoplastic elastomer, Arbomatrix, for the potential application of mitigating capsular contracture around the silicone breast implants. The sustained in vitro drug release profiles from these fibers (over 90% release in 21 days) followed close to a Fickian diffusion model. They also showed that Zafirlukast released from these drug-eluting fiber mats inhibited the target cysteinyl receptors in vitro. Electrospinning of a newly synthesized polyisobutylene-based thermoplastic elastomer, poly (alloocimene-b-isobutylene-b-alloocimene) or AIBA. AIBA is a highly hydrophobic triblock copolymer having high electrical resistivity, therefore they used poly (ethylene glycol) as the spinning aid, which was found to be encapsulated inside the AIBA fibers [18]. The tensile strength of these fiber mats (2.7 MPa at 537% elongation) was comparable to soft human tissues, and these fiber mats were also found to be non-cytotoxic in the cell culture studies using the mouse fibroblast L929 cells, thus showing a great promise for drug delivery applications.

ROLE OF FUNCTIONAL POLYMERS

Functionalized polymer surfaces comprised of super hydrophilic-superhydrophobic patterns with tunable wettability and functionality have attracted signification attention due to their applications in the field of biotechnology, biomedicine, high throughput screening, microfluidics, cell arrays, coatings, etc. Levkin et al., fabricated patterned superhydrophobic-super hydrophilic bio-functional surfaces via microcontact printing [19]. The micropatterns consists of super hydrophilic microarrays composed of lipid ink printed onto a solid superhydrophobic (porous BMA (butyl methacrylate)-EDMA (ethylene dimethacrylate)) substrate and are further utilized for cell screening. When these patterns are treated with water, only lipid ink printed regions retain water whereas the superhydrophobic background is unaffected by water, thus demonstrating the promise of such patterned bio-functional materials for lab-on-chip analysis, study of confined self-assembly, etc.

The porosity of the solid superhydrophobic substrates can be controlled by varying the ratio of porogens used during film preparation. Patterned surfaces with tunable porosity, surface roughness and optical activity can also be achieved using 2D phase-separation of polymer blend films and the pattern length scales can be tuned simply controlling annealing time, temperature, film confinement, etc.[20]. Surfaces with tunable wetting properties can also be achieved in a facile manner via self-assembly (phase-separation) of amphiphilic block copolymer films [21]. Amphiphilic block co-polymer films composed of FDF ('F'-poly (2-(N-ethylperfluorooctanesulfonamido) ethyl methacrylate (poly (FOSM)) and 'D'-poly (N, N-dimethyl acrylamide) (poly (DMA)) triblock copolymer exhibit a natural film thickness induced surface wettability. As film thickness increased, water contact angle (WCA) also increased and these films also exhibited dynamic water contact angle, i.e, WCA varied as a function of time.

While films of lower and higher thickness always remained hydrophobic and hydrophilic respectively, films of intermediate thickness transitioned from hydrophobic to hydrophilic regime as time elapsed after placement of water droplet on the film. This is due to the increase in surface coverage of hydrophobic/hydrophilic domains, domain size and surface roughness that determine surface wettability can be simply tuned by controlling film thickness. These films also possess optical properties with varying specular and diffuse reflectance that are associated with varying surface roughness [21].

GENETICALLY ENGINEERED BIO-POLYMERS

UV-reflectance materials are of primary interest in the fields of biomedicine, healthcare, cosmetics, etc. in light of the damage caused by photodegradation resulting in loss of physical, mechanical, chemical properties and exposure to harmful UV-light also has adverse impact on health. Since, currently used UV-additives are energy-intensive and not all of them are environment-friendly, there is a quest to find and use natural UV-protecting materials which will also have direct advantages when biomedicine is considered. Eggshells, in general, are considered to provide protection from mechanical and chemical damage to the material inside. Shawkey et al. [22], recently demonstrated that chicken eggshells offer good UV-protection and exhibit similar performance as titanium dioxide when UV-protection is considered. Furthermore, eggshells of two different colors examined (white, brown) demonstrated same UV-protection. Thus, chicken eggshells that are often treated as waste can serve as a useful, economical, viable, environment-friendly and a natural UV-protecting material. Potentially, the eggshell can be utilized as a multi-functional material with good UV-protection, chemical resistance, etc [23].

Recent developments in genetic engineering has favored towards the synthesis of recombinant spider silks, thus helping to understand the fundamental relationship between biomechanical properties and applicability of biopolymers. Spider silks represent the class of biopolymers that are inherently composite materials. Adhesion under high humidity conditions, such as on skin, is an unresolved challenge for synthetic adhesives. Synthetic adhesives show significant drop in adhesion above a critical humidity due to interfacial failure [24]. However, spiders are active in a variety of habitats, from dry to wet, and use glue on their web to catch prey that enables their survival. Interestingly, spiders glue uses a clever mix of physical and chemical design principles to enable adhesion under high humidity. First, the spider species tunes glue viscosity with humidity, such that diverse species have similar bulk viscoelasticity under spider's foraging humidity [25]. That is, spider from a dry habitat that forages under 30% relative humidity (RH), has the same glue viscosity as the spider glue of a spider that forages in wet conditions (~ 90% RH). Second, spider glue is a heterogeneously arranged aqueous mix of glycoproteins and low molecular weight hygroscopic compounds [26,27]. These hygroscopic small compounds not only plasticize the proteins, but also sequester water away from the surface, such that interfacial failure is avoided due to water plasticization [28]. Third, the proteins and hygroscopic small molecules interact such that the water uptake of spider glue is less than the individual components [29]. These design principles from spider glue are sparking interesting bio-mimics that will result in smart adhesives which work in wet conditions, especially on or inside the human body [30].

SUMMARY AND CONCLUSIONS

To summarize, biocompatible 3D polymer structures have found extremely critical in several applications ranging from delivery of therapeutic drug compounds, tissue regeneration, topical dressings etc., Recent developments in polymer engineered materials leading new vistas of material sciences with a vast scope and immense popularity. Electrospun polymer membranes that exhibit 5X the strength of soft human tissue, with promising non-cytotoxic characteristics reported in the recent past sounds promising. Phase-separated block copolymer films with interchangeable wettability characteristics serving as a reliable materials for internal organ regeneration. Genetically engineered smart adhesives that are UV, chemical resistant still requires more fundamental understanding before they go mainstream therapeutic usage.

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Cite this article

Lolla D (2020) Future of Polymer Materials in Bio-science Applications. JSM Nanotechnol Nanomed 7(1): 1075.