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Effective Drug Delivery System of Biopolymers Based On Nanomaterials and Hydrogels - A Review

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Abstract

Design and synthesis of well-ordered drug delivery systems are very important for medicinal and pharmaceutical and health care. Innovations of materials through nanotechnology and hydrogels have synergistically energized the growth of drug delivery. Uniqueness in material chemistry permits the creation of environmentally approachable, biocompatible, biodegradable and targeted drug delivery system. Large numbers of biopolymers have been examined for the design of drug delivery systems. Structure, size, shape and multi-functionality of drug delivery system can be controlled by the nanotechnology combined with biopolymer. Hydrogels have also been investigated as smart delivery systems capable to release, at the appropriate time and site of action, entrapped drugs in response to specific physiological triggers. This review mainly focuses on drug delivery applications of nanoparticles modified biopolymers and effective drug delivery system of biopolymer network based on hydrogels.

Keywords: Biopolymer; Drug delivery; Nanoparticles; Hydrogels; Structural design

Introduction

Pharmaceutical industries are continuously facing challenges and expectations of novel technologies and opportunities for development of drug designing due to medical and health care material research. The utilization of excipients in pharmaceutical industries evolves from their traditional auxiliary function in formulations like facilitating flowability and consistency of the product along with their vital role in enhancement of drug performance particularly stability, release and bioavailability. Nowadays bio-based materials are considered as key ingredients for the engineered drug delivery systems because of their stability, availability, renewability and low toxicity [1-3]. Suitable chemical modifications of biomaterials are very much needed with unique properties of their use in drug delivery system rather than their usual biodegradability and biocompatibility.

Drug delivery is a multidisciplinary field which constitutes knowledge from the field of chemistry, pharmaceutical sciences, medicine and engineering. It mostly depends on the chemical formulation of drug, dosage form and administration route. Drug delivery system ameliorate the problems of conventional administration by enhancing drug solubility, prolonging duration time, reducing side effects and retaining drug bioactivity. Nowadays, drug delivery system has enhanced bioavailability, improves the uptake, preserves drug concentration by controlling the rate of drug release and reduces side effects by releasing the drugs at target cells [4-7].

Innovative ideas in material chemistry have primarily motivated the arrival of biodegradable carriers, biocompatible drug development system (DDS), inducement and target responsiveness. The development of molecularly engineered biomaterials has been motivated by the challenges in controlled and intra cellular delivery of both hydrophobic drugs and macromolecular bio-therapeutics, such as proteins and nucleic acids [8,9]. Intelligent materials that can sense and respond to physiological and biological signals, demonstrate a promise in helping engineers and scientists overcome the significant challenges of achieving efficient administration of therapeutics.

Many different biomaterials, both natural and synthetic, both biodegradable and non-biodegradable, have been investigated as drug delivery systems for health care and tissue engineering applications, including bio-ceramics, great biocompatible and composite polymers and hydrogels. Biopolymers basically exhibit important properties such as biodegradability, biocompatibility and antibacterial activity. Chemical structure and compositions of biopolymers are very similar to the macromolecules of the native extracellular environment [10-13]. Utilization of these materials in living systems would reduce the simulation of chronic inflammation or immunological reactions and toxicity, frequently occurring when a synthetic polymer device is implanted into a host. Chemically modified biopolymers can be put right in mechanical and electrical properties requirement for particular applications and rate of degradation [14,15].

Nanoparticles are normally used in biological pathways (signaling pathways) to achieve drug delivery to cellular and intracellular targets, including transport through the blood-brain barriers. Owing to their small size, nanoparticles can easily enter host cells and circulate through the body [16]. They are suitable for site specific delivery vehicles to carry large doses of chemotherapeutic agents or therapeutic genes to the target sites. Biopolymers based nanoparticles have drawn great attention for drug carriers. The modification of nanoparticles with various types of biopolymers can also contribute in their efficiency. Many biomolecules, including proteins, enzymes and oligopeptides [16,17], antibody and antigens and DNA/oligonucleotides/aptamers have been immobilized on the surface of nanoparticles to form nanoparticle-bimolecular conjugates [16,18].

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Hydrogels play vital role in the development of drug delivery system. Recently a significant research focused on the utilization of bio-based hydrogels for various biomedical applications. Hydrogels can be grafted onto biomaterials by physisorption, physical entrapment, graft coupling and polymerization [19,20]. Natural hydrogels, in particular different derivatives of the extra-cellular matrix, such as protein and polysaccharide materials have proved suitable in terms of medicinal applications. The principal market of biomaterials is in the areas of cardiovascular implants, orthopedic implants, intravascular, urinary tract catheters, wound dressing, biosensors and controlled release devices. The biocompatibility of these biomaterials can be improved by coating with hydrogels [15,19,20].

This paper provides a short review on the use of biopolymers, nanoparticles modified biopolymers, and hydrogels grafted biomaterials and their potential as a drug delivery system.

Drug delivery applications of biopolymer modified with nanoparticles

Biopolymers modified with nanoparticles (NPs) make possible their use for different applications like catalysis, optics, electronics, antimicrobial activity and drug delivery [16,21] (Figure 1). Drug delivery system provides productive attachment for therapeutics including drugs, proteins and nucleic acids with different roles like improvement of solubility, enhancement of *in vivo* stability, optimization of bio-distribution and pharmacokinetics of drugs [16,22]. In recent years, interest has been stimulated by the capability of the NPs to bind a wide range of organic molecules, their low toxicity, and strong and tunable optical absorption. This has resulted in a broad array of studies in which NPs have played an important role as drug and vaccine carriers into target cells or specific tissues [16,23]. Table 1 summarizes various nanomaterials and their important biomedical applications in drug delivery system.

Vimala et al. [24] studied the antibacterial activity of curcumin-loaded nanoparticles by integrating them into the protein hydrogel. Multifunctional polyelectrolyte thin films were fabricated by the electrostatic adsorption of poly (allylamine hydrochloride) (PAH) and dextran sulphate (DS) to load and deliver therapeutic drugs [25]. Biogenic silver nanoparticles were synthesized by using the leaf extract of Hybanthus enneasermus and they were effectively incorporated into the prepared thin film. Thus, conjugated AgNPs with multilayer films showed an efficient delivery and release of antibacterial drug such as moxifloxacin hydrochloride (MH). The AgNPs-polyelectrolyte thin films showed higher release of total MH rather than AgNPs alone.

Modified AgNPs were also found to be strong antiviral agents

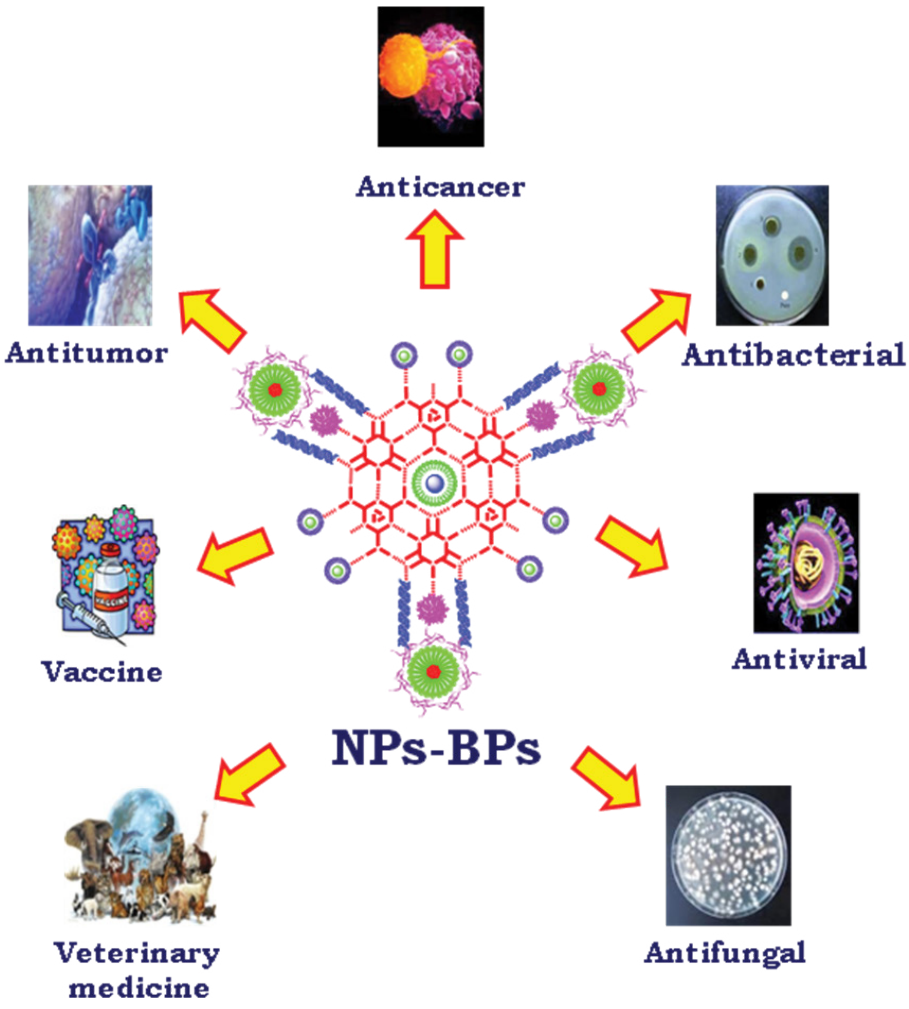

Figure 1: Schematic illustration of drug delivery applications of biopolymer modified with nanoparticles.

Biomedical applications	Types of nanocomposites	References
Antibacterial	Protein-AgNPs	Vimala et al. [20]
Antibacterial	PHA and DS-AgNPs	Sripriya et al. [21]
Antiviral	Foamy carbon-AgNPs PVP-AgNPs Bovin serum albumin-AgNPs	Elechiguerra et al. [23]
Antiviral	MES-AgNPs	Baran-Pinto et al. [24]
Antifungal	Miconazole-AgNPs	Kumar et al. [25]
Anticancer	PAuNPs 5Fu@PAuNPs	Ganeshkumar et al. [29]
Anticancer	5Fu-polylactic acid-co-ethylcellulose-AuNPs	Sathishkumar et al. [30]
Antibacterial	PLGA-TNT-Ti Chitosan-TNT-Ti	Kumeria et al. [33]
Antibacterial and antifungal	TG-ZnO nanorod	Ghayempour et al. [34]
Anti-tumor	QC-OREC NPs	Xin et al. [35]
Anticancer	Curcumin loaded TRC-NPs	Rejinold et al. [36]
Vaccine	HB:PR, HB:PR:DS, HB:PARG:ALG, HB:PARG:Pic	Correia-Pinto et al. [40]
Vaccine	Gelatine-sodium alginate gross linking polymer	Boesteanu et al. [41]
Veterinary medicine	S-g-PAA	Gok et al. [42]

Table 1: Types of various nanocomposites and their important biomedical applications in drug delivery system.

when compared with bare AgNPs, and AgNPs can act as the protective nanoshield against virus infection [26]. Elechiguerra et al. [27] studied the antiviral activity of AgNPs incorporated with three different polymers, namely foamy carbon, poly(N-vinyl-2pyrrolidone) (PVP) and bovine serum albumin (BSA), against Human Immunodeficiency Virus type 1 (HIV-1). Baram-Pinto et al. [28] also designed mercaptoethane sulfonate (MES) modified AgNPs and tested them against Herpes Simplex Virus type 1 (HSV-1). In antiviral assays, virus was treated with MES-coated AgNPs at different time intervals to analyze the block at different stages of the viral infection. The synthesized AgNPs have proved the strong ability to inhibit HSV-1 infections through prevention of binding and entry of virus into host cells.

Micronazole-conjugated AgNPs were prepared by Kumar and Poornachandra [29] from cell free supernatant Delftia sp. Strain KCM-003. They analyzed prospective of the prepared Ps as an antifungal agent as well as drug delivery vehicle. AgNPs exhibited as a significant antifungal activity agent against various pathogenic Candida species. They also observed that the antifungal activity of these AgNPs significantly increased with the conjugation of antifungal drug miconazole. Moreover the analysis of immunocytochemistry and cell viable tests against different normal cell lines including Chinese hamster ovary cells (CHO), human lung cell line (MRC5) and human vascular endothelial cells (HUVEC) confirmed that these AgNPs were harmless up to a concentration of 20 mM.

Biomedical applications of gold nanoparticles (AuNPs) are also increasing, as drug delivery agents, for diagnosis of heart diseases, cancers and infectious agents, and in cancer therapy [30,31]. Novel polysaccharide-Au nanocluster supreamolecular conjugates with AuNPs behaving adamantine moieties and β-cyclodextrin grafted hyaluronic acid (HA) were developed by Li et al. [32]. Numerous anticancer drugs can be loaded on these NPs conjugates due to its porous nature. The drug loaded AuNPs conjugates efficiently inhibited the growth of MCF-7 cells, drug releases were enabled in cells with pH responsive and drug toxicity also decreased to normal cells due to the high efficiency of their cellular uptake by HA reporter-mediated endocytosis. Ultrafast synthesis of AuNPs using *Punica granatum* was developed by Ganesh kumar et al. [33] as a target drug delivery system for anticancer treatment. The developed *Punica granutum* mono-dispersed AuNPs (PAuNPs) were evaluated their hemocompatibility behavior with human blood samples and found that the PAuNPs were well hemocompatible. The toxicity behavior of PAuNPs, 5-Fluorouracil (5-Fu) and 5- Fluorouracil@PAuNPs were analyzed using Zebra fish embryos. The investigation of *in vitro* toxicity behavior of free 5-Fu and 5-Fu@PAuNP were carried out against MCF-7 cells and found that the requirement of 5-Fu@PAuNPs was much lower than Free 5-Fu to achieve 50% of growth of inhibition. 5-Fu@PAuNPs proved as a promising carrier for targeting breast cancer treatment. 5-Fluorouracil entrapped polyacetic acid-co-ethylcellulose nanocapsules were prepared with and without AuNPs through solvent evaporation method by Sathiskumar et al. [34]. They characterized and investigated the controlled release of anticancer drug of entrapped nanocapsules and they found that the drug release for nanocapsules containing AuNPs was controlled and slower than 5-Fu encapsulated polymeric nanocapsules without AuNPs.

Eco-friendly biopolymer, guar gum (GG) was utilized as a precursor to produce a highly stable dispersion of platinum NPs (PtNPs) due to its reducing and capping behavior in the aqueous medium. DNA programmed assembly of nanostructures were prepared PtNPs modified with a distinct number of DNA ligands and the DNA PtNPs showed an excellent stability against DNA detachment [35]. Programmable Au–Pt bimetallic structures could be prepared through one-step assembly of highly compatible DNA decorated Pt and Au nanoparticles. The molecule-like discrete structures with defined bonding valences for all constituent particles are attractive for applications relating to their combined catalytic and other properties [36].

The antibacterial properties of titania nanotubes–titanium (TNT–Ti) samples coated with two biopolymers such as polylactic-co-glycolic acid (PLGA) and chitosan were evaluated with respect to bare Ti, bare TNT–Ti, TNT–Ti loaded with gentamicin and d-α-tocopheryl polyethylene glycol 1000 succinate (TPGS)-gentamicin micelles. The combination of gentamicin or TPGS-gentamicin with chitosan packs inside the TNT has shown a significant enhancement of antibacterial activity. They can be used as a potential candidate for biomedical applications, particularly in the field of deliver therapeutics, implant-related infections and osteointegration [37]. The excellent stability of *Tragacanth gum* (TG) biopolymer is useful for the preparation of different materials used as stabilizer, emulsifier and thickener. Urchin-like zinc oxide (ZnO) nanorod arrays were synthesized by sonosynthesis method using the TG as a reducing as well as a stabilizing

agent. The synthesized ZnO nanorods in the presence of TG showed a good antibacterial and antifungal activity against *E.coli, S. aurueus* and *C. albicans*. The lower cytotoxicity effect was recorded by the synthesis of urchin-like ZnO nanorod arrays in the presence of TG against the cytotoxicity assay. It has proven as a promising material for antibacterial and antifungal activity [38].

Layer-by-layer deposition technique was used to prepare Quaternized Chitosan (QC)-organic rectorite (OREC) intercalated composites based nanoparticles immobilized with cellulose acetate nanofibrous mats through hydrogen bonding. The assembled nanofibrous have shown well antitumor activity with good biocompatibility. NPs assembled nanofiber mats were admirable attuned with normal cells, they could selectively kill human carcinoma epithelial cells and had excellent blood compatibility. These characteristic behaviors were explained by MTT assay, cell culture experiments and hemolysis test. QC-OREC NPs assembled nanofibrous mats can be considered as a new alternative method for cancer therapy [39]. Rejinold et al. [40] developed a curcumin-loaded biodegradable thermo-responsive chitosan-g-PNVCL nanoformulatin for cancer drug delivery. The results of MTT- and FACS based apoptosis assay and methanol based UV assay are confirmed that curcumin-loaded TRC-NPs could be more advantageous for cancer treatment by an appropriate combination therapy with hyperthermia.

Vaccination is the most cost-effective preventive intervention against disease to date [41], and while the majority of the marketed vaccines are based on attenuated and inactivated whole-cell vaccines, the current tendency is to design vaccines based on subunit antigens. Subunit vaccines are based on specific components of pathogens, and are less prone to provoke adverse reactions [42]. Among the subunit antigens, virus-like particles formed by self-assembled viral proteins, are particularly interesting due to their superior immunogenicity [43]. Correia-Pinto et al. [44] prepared multi-enveloped nanoparticles (HB:PR; HB:PR:DS; HB:PARG:ALG; HB:PARG:pIC) of very small size and they were found to be internalized by macrophages. Antigen delivery nanocarriers having very small size might not be a good option for enhancing the immune response against particulate antigens. Development of novel vaccines is very much needed because of the increasing chances of an influenza virus pandemic and the potential danger of using as a bioterrorism agent, an easily infectious virus such as influenza virus. Existing influenza virus vaccines mainly bring out the antibodies and can be delivered unproductive by antigenic drift and shift. The live influenza virus was successfully encapsulated in a biopolymer by Boesteanu et al. [45] and delivered it to mice subcutaneously to verify the reactivity against different influenza virus strain. The developed vaccine has proven very safe, stimulates effective CD8+T cell immunity and protected mice against heterosubtypic lethal challenge. Encapsulation of live influenza virus with biopolymer can be utilized to develop universal CD8+T cell vaccine in opposite to heterosubtypic and pandemic strains.

The design of drug delivery devices and formulations in the veterinary medical research has long and well-known history. Economically viable polymers can be used to develop therapeutically efficient implantable devices for delivery of steroids, antihelmintics and production of antibacterial drugs with creative design. Mucoadhesive, biocompatible and biodegradable starch-graft-poly (acrylic acid) (S-g-PAA) copolymer fabricated vaginal tablets were prepared by Gok et al. [46]. Frequently used vaginal formulations in veterinary medicine such as CIDR containing 330 mg progesterone and sponge containing 20 mg flugesterone acetate were compared with the prepared mucoadhesive tablet through *in vitro* and *in vivo* progesterone release study. The results indicated that the prepared mucoadhesive vaginal tablet formulation can be a better alternative rather than the commercially available vaginal formulations.

Effective drug delivery system of biopolymer network based on hydrogels

Hydrogels based biodegradable polymeric materials are an important research area of macromolecular network and they can be used in a suitable way in the field of biomedical applications including control drug delivery due to their potential to stimulate biological tissues. Design and fabrication of hydrogel based materials should meet the essential requirements of pharmaceutical and medical fields. Table 2 summaries, various hydrogels and their important applications in the biomedical and pharmaceutical field as a drug delivery system and the schematic illustration have shown in Figure 2.

Hydrogels were prepared with pH sensitive nature based biopolymers using chitosan (CS) with polyethylene glycol (PEG) as a repealing agent of immunogenic protein with different molecular weights in the presence of silane cross linker. An acidic pH, the prepared hydrogels showed high swelling nature, whereas low in basic pH. This pH responsive nature is very useful in the injectable controlled drug delivery system. The formulated hydrogels can be promising biomaterial for injectable drug delivery at physiological pH. It was confirmed by the controlled release analysis of developed hydrogel with model drug cefixime showed that the whole drug was released within 30 minutes in stimulated gastric fluid, 85 % of the drug was released at 80 minutes in simulated intestinal fluid in a controlled way [47].

Covalently-cross linked mucin hydrogels were prepared by Duffy et al. [48] in the presence of free radical photoinitiators under ultraviolet light exposure of methacrylated mucin. The prepared hydrogels were proteolytic degraded by pronase and they behaved as a soft mammalian

Biomedical application	Model drug used	Types of hydrogels	References
Antibacterial	Cefixime	CS/PEG	Atta et al. [43]
Antibacterial and anticancer	Polymyxin and paclitaxel	Methacrylated mucin	Duffy et al. [44]
Anti-inflammatory	Indomethacin	TGAP and TGAP-GDE	Hosaini et al. [45]
Antibacterial	*Escherichia coli* and *staphylococcus aureus*	CS-ZnO NPs	Yadollahi et al. [46]
Antibacterial	*Escherichia coli* and *staphylococcus aureus*	CS-Ag NPs	Yadollahi et al. [47]
Anti-inflammatory	Diclofenac sodium	CMC-AgNPs	Gulsonbi et al. [48]
Respiratory activity	Theophylliine	CNC-Gt	Ooi et al. [49]
Anti-inflammatory	Indomethacin	PLGA-NH_2-Gt	Chung et al. [50]
Anti-inflammatory and anticancer	5-Fluorouracil and diclofenac	CMCS-$PNIPA_m$-GMA	Zhang et al. [51]
Anti-inflammatory	Aspirin	CD-g-CMCs	Kono et al. [52]

Table 2: Types of various hydrogel and their important biomedical applications in drug delivery system.

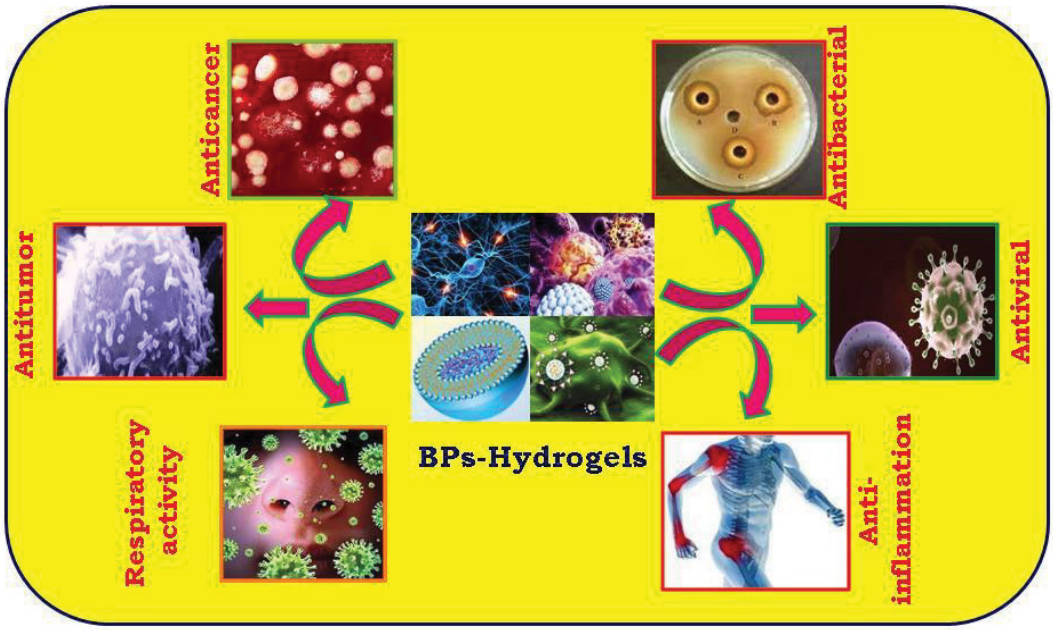

Figure 2: Schematic illustration of drug delivery system of biopolymer network based on hydrogels.

tissue. These hydrogels are retained and released linearly both paclitaxel and polymyxin B drugs with time over seven days. Even after four weeks, the hydrogels actively released sufficient amount of paclitaxel to reduce HeLa cell viability and adequate amount of polymyzin B to prevent bacterial production. Nowadays immunocompatible mucin based biomaterials moreover complex with multifunctional synthetic polymers are very much useful for the biomedical applications due to their chemical versatility and natural multi-function nature.

Hosaini et al. [49] were prepared pH responsive nanohydrogels with biopolymer tragacanth gum for drug delivery system using 3-aminopropyltriethoxysilane as a modifier and glycerol diglycidyl ether, polyvinyl alcohol and glutaraldehyde as a cross linker. The nanogel contents were increased with respect to increase of cross linker and reached at a maximum of 90% due to the formation of an interpenetrating network with chemical cross linking between tragacanth gum and cross linkers. The swelling behavior of nanohydrogels at various pH were investigated and observed significant increase at pH 7.4 and 9. Indomethacin was used as a model drug to investigate the drug releasing potential of prepared nanogels by *in vitro* study. The total indomethacin released at pH 9 after 24 hours it has shown the nature of drug release was highly dependent based on the network structure of nanohydrogels and the pH.

Yadollahi et al. [50] were synthesized chitosan-zinc oxide nanocomposites (ZnONPs) hydrogels by *in situ* formation of ZnONPs in the chitosan hydrogel matrix to investigate the potential of drug delivery applications. Ibuprofen was used as a model drug to investigate the drug releasing performance of prepared hydrogel beads. The swelling activities of the synthesized hydrogels attained maximum at pH 2.1, this is due to the protonation of amine groups in chitosan which leads to chain repulsion. Drug releasing actions of prepared hydrogels were highly depended upon the content of ZnONPs. The content of ZnONPs was increased in the hydrogels, the potential of controlled drug release also increased. Yadollahi et al. [51] were also prepared chitosan-silver nanocomposite hydrogels via *in situ* formation of AgNPs in the chitosan hydrogel environment with sodium tripolyphosphate as a cross linker. The swelling behavior of the prepared hydrogel beads was also higher at pH 2.1. The *in vitro* antibacterial activity is highly influenced by the concentration of AgNPs. Hydrogels contain more AgNPs showed higher antibacterial properties. It was demonstrated against *Escherichia coli* and *Staphylococcus aureus* bacteria. *In vitro* drug release test also carried out using ibuprofen as a model drug. The prepared chitosan-Ag nanocomposite hydrogels could be promising material for controlling delivery of drugs. Size controlled silver nanoparticles were synthesized using neem plant extracts as a reducing agent inside the hydrogel templates containing carboxyl methyl cellulose (CMC) polymeric networks. Swelling behavior of silver hydrogel nanocomposite (SHN) greatly improved depending upon the CMC amount and silver ion concentration. Maximum degree of swelling was observed at pH 8 due to anion-anion repulsive forces between the groups in the network of the hydrogels. Diclofenac sodium was used as a model drug. The response of the prepared SHN against pH made it suitable for the release of diclofenac sodium (DS) in the colon environment [52].

Cellulose nanocrystals (CNC)-gelatin (Gt) hydrogels has shown excellent pH sensitivity with a maximum swelling ratio at pH 3. The ability of the CNC-Gt hydrogel to respond to different pH values along with its high dynamic mechanical stability suggested that CNC-Gt hydrogels are promising candidates as drug carriers. Drug carrying property of CNC-Gt hydrogels are examined with theophylline used as a model drug. Among the various preparations of CNC-Gt hydrogels with different ratios, 15% CNC reinforced Gt hydrogels were proved as the best potential candidate for controlled drug delivery system [53]. Another study was carried out about the preparation of Gt-poly (lactic-co-glycolic acid) (PLGA) and aminolated PLGA hydrogels for the drug delivery of hydrophobic drugs. Indomethacin (IDM) was used as a model drug and it is cross linked with various concentrations of 1,6 hexamethylenediisocyanate (HMDI) in a DMSO solution. High IDM encapsulation efficiency was recorded by the biocompatible Gt-PLGA-NH_2 hydrogel film with low burst release and the high accumulative release of IDM. Concentration of HMDI was highly influenced in release of IDM from the prepared hydrogel films [54].

Zhang et al. [55] developed a localized drug delivery system with cytocompatible thermo and pH responsive injectable hydrogels based on carboxylmethyl chitosan and poly (N-isopropyl acrylamine)-glycidyl methacrylate)-glycidyl methacrylate by photocrosslinking under a UV lamp for anticancer and anti-inflammatory drugs. 5-Fluorouracil and diclofenac sodium are encapsulated in the hydrogel by *in situ*. Live/Dead assay kit and Alamar blue measurement by dog bone marrow mesenchymal stem cells were used to estimate the cytocompatibility of the macro monomer carboxylmethyl chitosan- poly(N-isopropyl acrylamine)-glycidyl methacrylate)-glycidyl methacrylate as well as their hydrogels. The prepared cytocompete injectable hydrogels are proved as a promising material for localized drug delivery system with great potential.

Kono et al. [56] were prepared β-cyclodextrin-grafted carboxymethyl chitosan hydrogels (CD-g-CMCs) using a water soluble carbodiimide in the presence of N-hydorxyl succiniimide. The prepared hydrogels were examined for their potential use as carriers for drug delivery system. The CD-g-CMCs showed an excellent drug carrier property with aspirin and exhibited slow and sustained release of aspirin due the formation of host-guest complex between aspirin and the hydrophobic cavity of β-cyclodextrin in the hydrogels. The CD-g-CMCs proved as a potential drug carrier with a control drug releasing ability.

Conclusion

Biopolymers based nanoparticles and hydrogels are promising tools for various biological applications; they have the capability to be used for drug delivery purpose and they showed significant antiviral, anticancer, antibacterial, antimicrobial and antifungal activity. They also possess a high content of functional groups that can be utilized for cross linking with additional functional cross linkers as well as for further bio-conjugation with cell targeting agents. This review has summarized various techniques for synthesis of novel biopolymer based nanoparticles and hydrogels and also explained the successful adoption in drug delivery system by these materials. Future research on biopolymer based delivery systems should focus on developing new methods for fabrication and refining or adapting current methods for their application to medical, pharmaceutical as well as food and food products.

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