Review Article

Cancer and the Role of Polymeric-Carriers in Diagnosis and Treatment

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Abstract

With the daily advancement of science and the use of different sciences in medicine, new achievements are made for the treatment of human beings. One of the pioneering sciences in this field is polymer engineering, these magical macromolecules can be designed to be used in a variety of fields. They can be used as a prosthesis, drug carrier, gene delivery, etc. In recent years, they have come to the service of medicine to diagnose and treat cancers. Polymers are a good candidate for the release of anti-cancer drugs. Timely release, non-toxicity, and biodegradability are important features of a carrier. These properties are found in many synthetic and natural polymers and can be used by designing their structure for a unique application. This study summarizes cancer statistics in the United States and Iran, and introduces several polymer-carriers such as dendrimer, chitosan, and micelle used in the diagnosis and treatment of cancer.

Keywords: Cancer, Polymer, Dendrimer, Chitosan, Micelle

Introduction

1. Cancer report

In recent years, with the destruction of forests, weather change, and environmental pollution, human health is increasingly at risk. Improper nutrition, constant usage tobacco and alcohol, which are often due to modern human life, have caused many diseases (1-6). Cancer has been associated with human life for more than two decades and has become a major public health problem in the world. Every day, many people in different parts of the world are going to die from cancer. Chart 1 shows the forecast for new cases and deaths from cancer in the United States from 2010 to 2020 (7-17). Shocking statistics with the death of approximately 1600 individuals per day. In the United States, cancer is one of the five leading causes of death in all age groups (7,17).

The highest number of cancer deaths was in 1991 (12), but over time and with medical advances, screening tests, human awareness of changing nutrition patterns, and reduced use of cigarettes and alcohol have largely improved (17). Until 2013, with timely diagnosis and treatment, they have prevented the deaths of nearly 117,7300 humans (10). Chart 2 shows the most common cancers in men and women in the United States (7-17). A decrease in the incidence of common cancers indicates an improvement in cancer prevention (11). The change in the incidence of lung cancer in men and women is due to differences in the use of tobacco in them, also there has been a significant difference in lung cancer statistics in the states, for example, until 2010, Utah had the lowest and Kentucky had the highest number of cases, due to the lower use of tobacco in Utah (7).

The rate of cancer and mortality in races and social classes is very different, for example, this statistic is much higher in African American men and women, due to inequalities in access to and receipt of quality health care, screening tests, and from differences in comorbidities (7,17). Unfortunately , despite many advances in cancer

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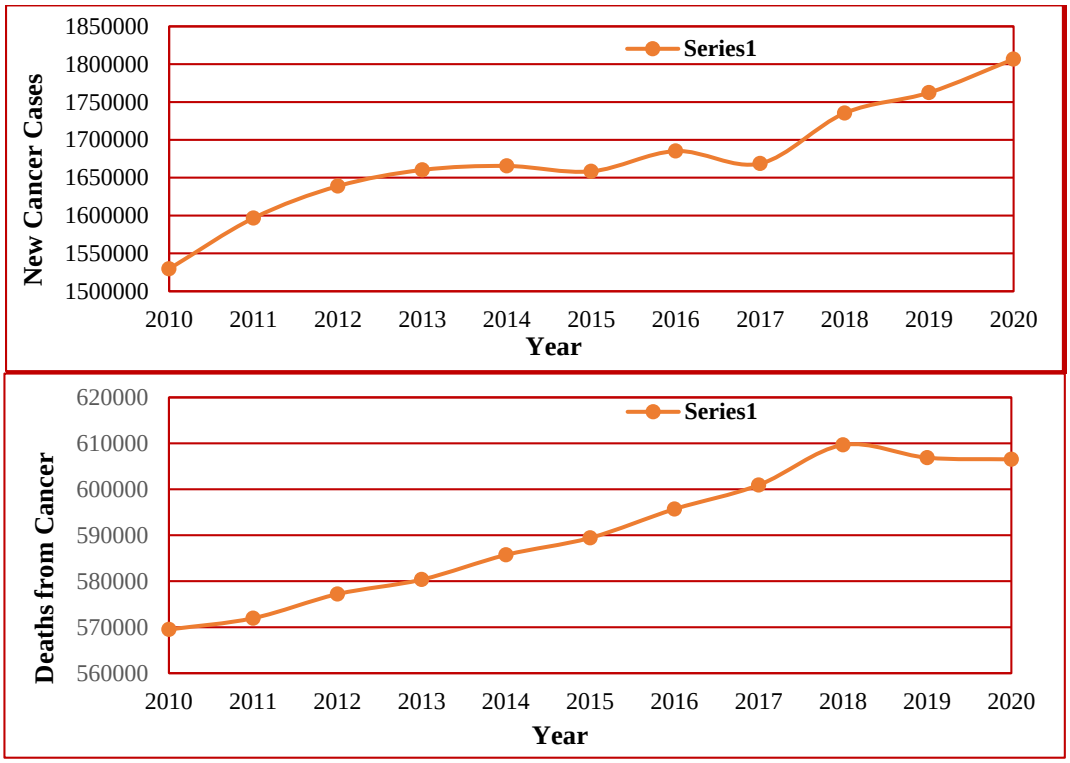

Chart 1. Estimated New Cancer Cases and Deaths in the United States from 2010 to 2020

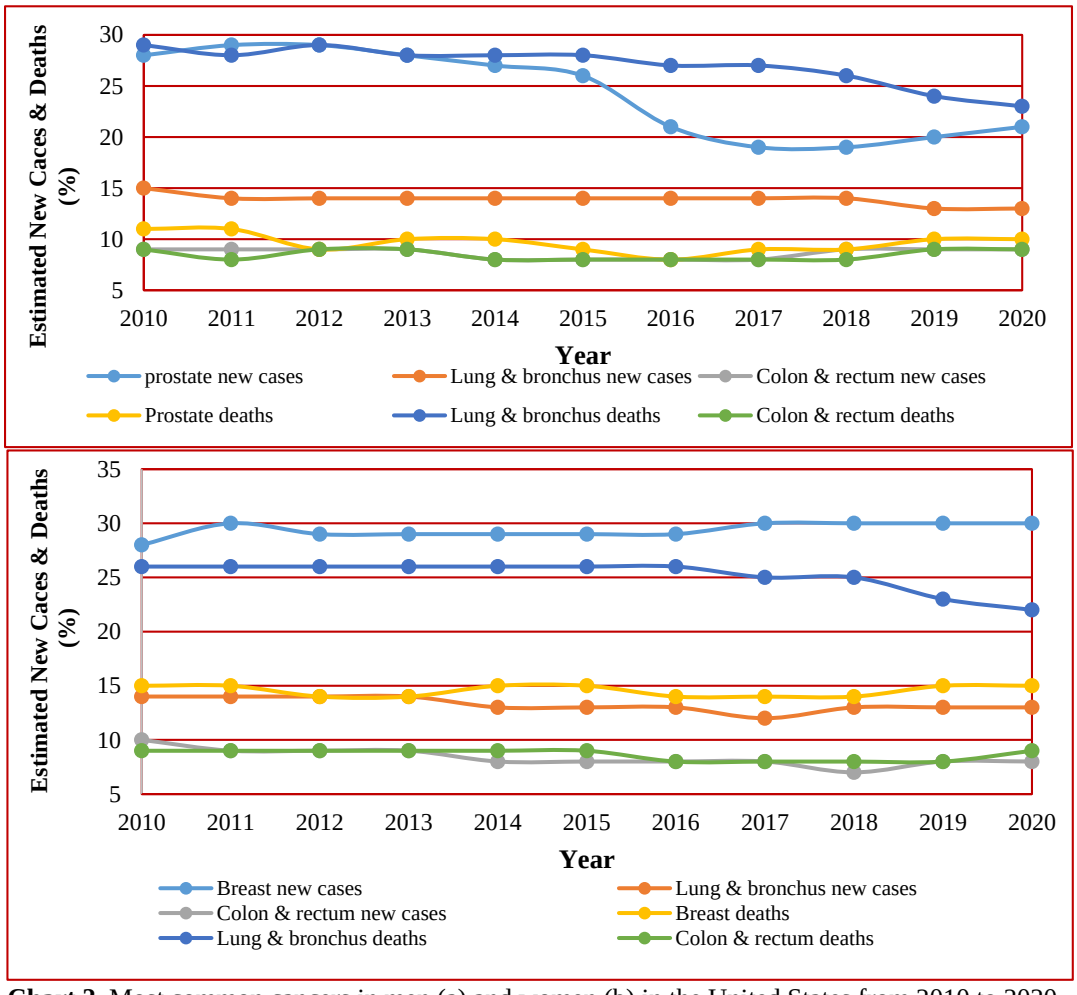

Chart 2. Most common cancers in men (a) and women (b) in the United States from 2010 to 2020

diagnosis and treatment, the cost of services and treatment remains high, so the golden time for early diagnosis and treatment is lost (7,12,17). The second leading cause of death among children aged 1 to 14 in the United States is cancer. Leukemia is the most common childhood cancer, followed by cancer of the brain and other nervous systems are next (7-17). According to published statistics, unfortunately, it can be seen that all ages can get this disease. International Agency for Research on Cancer in 2018, presented a report with a focus on geographic variability across 20 world regions, about 18.1 million new cancers were predicted (17.0 million excluding nonmelanoma skin cancer) and 9.6 million cancer deaths (9.5 million excluding nonmelanoma skin cancer), which lung and breast cancer is the most common cancer and the leading cause of death in men and women (18). The prevalence of cancer and mortality in Asia, according to the 2018 Globocan evaluation, is at 48.4% and 57.3%, respectively (19). In Iran, cancer is the third leading cause of death after a traffic accident and cardiovascular mortality (19,20). Breast, colorectal and stomach cancers are the most common cancers in Iran for women, and stomach, prostate, and colorectal cancers are the most common cancers in men, also there has been a growing trend in breast and colorectal cancers (19). The high rate of stomach cancer in Iran can be partly due to the high use of homemade and non-standard alcoholic drinks. Also, cancers of leukemia, lymphoma, and central nervous system neoplasms are the most common cancers in children under 15 years of age have been reported (20). Over the years, cancer treatment has progressed amazingly, one of which is chemotherapy, which can destroy tumors and arrest cancer progression (21). However, in conventional chemotherapy drug is distributed as general in the body, and because some drugs are toxicities or have serious side effects, they can also affect normal cells, and that these side effects cause to restrict the frequency and size of dosages, which is very detrimental to tumor destruction (21,22). For example, doxorubicin is one of the most widely used drugs for the treatment of multiple cancers, which has serious side effects such as heart damage (23). In recent years, the use of nanotechnology to diagnose and treat cancer has made significant progress. Nanoparticles can penetrate cancer cells and increase the concentration of drugs in them while preventing toxicity in normal cells, and they also have the ability to carry one or more various drugs (22,24). But, nanoparticles still have many limitations such as instability in circulatory system and toxicity (21,22,24). Carbon nanomaterials such as nanotubes, expanded graphite, graphene, and graphene oxide are among the nanoparticles that due to their unique properties, have many applications in the field of nanocomposites and medicine (24-29). Some of their medical applications include cancer diagnosis, colorimetric detection of cancer cells, and cancer imaging (30-32). Among these, polymer-carriers have a special place. Polymers have many applications in the medical field for reasons such as biodistribution and biocompatibility. They can be good carriers and prevent premature destruction of the drug and improve their stability and prolong the presence of the drug in the circulatory system. In addition, they can accumulate more in tumor cells, which is due to greater permeability (33). Polymeric carriers act differently in terms of drug release methods. Generally, we can say that drugs are graft to them, and with changes such as temperature, pH, etc., this bond is destroyed and the drug is released or polymeric carriers act as Trojan horses and deliver the drug to the target cell. The top polymer-carriers can be classified into three groups: dendrimers, chitosan, and micelles, which we will briefly introduce.

2. Polymeric-carriers

2.1. Dendrimer

Dendrimers have received a lot of attention in the last three decades. They consist of three parts including core, interior layers composed of repeated branching units, and terminal groups (34). In fact, they are spherical macromolecules with multiple arms from the central core. Each step of their synthesis creates perfect branches, and with the stepwise progress, the next generations (each layer is called one ”generation“) emerge (34,35). Polydispersity index, number of end functional groups of dendrimers, and the molecular weight can be controlled during synthesis. This unique architecture makes dendrimers new scaffolds for drug delivery. In the past, dendrimers had only one terminal group, which limited their use (36,37). But, with the advent of a new generation of dendrimers, known as Janus, the problem of application limitations has been resolved (38,39). In fact, they are a combination of two dendrons combined with a core. Dendrimers are biocompatible and usually soluble in water, they

are designed to be degradable, that is, due to thermal or chemical changes, the bonds between drug and dendrimer are destroyed and the drug is released (34). Convergent and divergent methods are two methods of synthesizing different types of dendrimers (40,41). In the convergent method, it begins with a polyfunctional molecule that acts as a core on which consecutive layers of monomer units are chemically bonded (40,42,43). The repetitive sequence of two reactions is used to add generations to the core, which correspond to the activation of the functional groups and their subsequent assembly with the other monomers (40,42,44). In the divergent method, obtaining the dendrons is via repetitive reactions, which are joined later to a central core consisting of a polyfunctional molecule (41,42). Both methods have their advantages. In the divergent method, high molecular weight products can be obtained at the nanometer scale (42). But, the main disadvantage of the divergent method is that terminal functional groups cannot always be reacted stoichiometrically, leading to structural defects (42,43). Convergence method is commonly used only to form dendritic structures of low generations, since steric hindrance limits the coupling of bulky dendrons to a core of reduced dimensions (42). Positively charged dendrimers possess considerable cellular cytotoxicity, hence the formulation of dendrimers negatively charged on the surface has been proposed as a way to increase the viability of healthy tissues (42). The above issues show that many points must be considered to design a dendrimer in order for this polymeric carrier to be usable. Pooresmaeil et al. (45) studied the new glycodendrimer containing β-cyclodextrin. For this purpose, graphene quantum dots were synthesized through pyrolysis of the citric acid, and then the polyamidoamine dendrimer was grown from the surface of the modified graphene quantum dots. Finally, the prepared graphene quantum dots-polyamidoamine was functionalized with β-cyclodextrin to obtain the glycodendrimer. 61.2 % of doxorubicin was loaded in the prepared glycodendrimer. The graphene quantum dots had a uniform spherical morphology with an average size of 5 nm. After the growth of the dendrimer from the graphene quantum dots surface, spherical morphology was relatively maintained but the size was increased 55 nm. Glycodendrimer had a relatively rougher surface in comparison with graphene quantum dots. The results showed that the glycodendrimer is a safe carrier with a good capability in penetration to the cancer cells. Moreover, glycodendrimer/doxorubicin exhibited more efficiency in the killing of the cancer cells compared to neat doxorubicin. Karimi et al. (46) studied a novel magnetic carbon modified. This magnetic carbon modified with *3-aminopropyltrimethoxysilane* using maltose disaccharide molecule, and a third-generation triazine dendrimer was then covalently attached to their surface. Finally, it reacted with graphene quantum dots for the preparation of final microspheres. The average height of prepared microspheres was 189.2 nm. Also, the microspheres were spherical in shape. Doxorubicin loading efficiency in microspheres was reported to be about 63.09%. The results showed that microspheres can be used as a new safe and efficient vehicle for the delivery of different cancer drugs. Guo et al. (47) studied a novel dendrimer nanoparticle. Hyaluronic acid-modified amine-terminated fourth-generation polyamidoamine dendrimer nanoparticles were synthesized for systemic co-delivery of cisplatin and doxorubicin. After doxorubicin loading, the particle size was about 106 nm. The results showed that nanoparticles/doxorubicin can enter the cells through the lysosome mediated-pathway in a time-dependent manner. Moreover, cell viability studies indicated that nanoparticles/doxorubicin exhibited a higher anticancer activity on MCF-7 and MDA-MB-231 breast cancer cells at a relative low concentration. Pishavar et al. (48) studied a Polyamidoamine-based dendrimer. Polyamidoamine modified with cholesteryl chloroformate and alkyl-ethylene glycol was applied for co-delivery of doxorubicin and plasmid encoding TRAIL (factor-alpha-related apoptosis-inducing ligand) into colon cancer cells, in vitro and in vivo. The size of complexes was about 118-164 nm with positive zeta potential and relatively narrow size distributions. The results showed that the treatment of mice bearing C26 colon carcinoma with these complexes significantly decreased tumor growth rate.

Dendrimers are commonly used to deliver potent anti-cancer drugs such as cisplatin and doxorubicin, gene delivery, photodynamic therapy, and magnetic resonance imaging (34,35).

2.2. Chitosan

Chitosan is a biological polysaccharide that has been widely used in medicine for more than a decade (49). This biopolymer is commonly found in the crustacean shells, exoskeletons of arthropods, insects, and fungal cell walls (50). Chitosan is composed of N-acetyl-d-glucosamine and D-glucosamine units with one amino (NH_2) group and two hydroxyl (OH) groups in each repeating glycosidic units, and due to the presence of reactive amine groups, chitosan is the only natural cationic polymer (51,52), but, the cationic property of chitosan can be reversed via sulfonation to introduce anionic character (52). The sources from which chitosan is obtained and the method of preparation have a direct effect on determining their molecular weight (52,53). Golden parameters such as non-toxicity, biocompatibility, being antibacterial, and biodegradability make chitosan a good candidate for drug delivery (54,55). Also, its biological adhesion makes chitosan easily adhere to soft and hard tissues and can be used in orthopedic, dental, and ophthalmic fields (51). Various forms of chitosan such as hydrogels, films, microspheres, and nanoparticles, are used as drug carriers, too (52). Hydrogels Polymeric networks are able to absorb water with the physical and chemical interaction between their networks, and the properties of polymeric hydrogels depend on the molecular weight, degree of crosslinking, charges, and association (56,57). The two parameters of molecular weight and degree of deacetylation directly affect the pH values, turbidity, viscosity, and thermosensitive properties of chitosan hydrogels (51,58). Swelling of chitosan can be affected by structure because network porosity and mesh size of the network controlled the swelling behavior. This parameter is very important in drug release (51). Chitosan hydrogels can keep the drug in the circulating system for a longer period of time and easily release the drug under different stimuli (59). Chitosan films have another form of use. They have excellent ability to form film and have many applications in drug delivery systems such as antibiotics, ibuprofen, and lidocaine (60,61). Chitosan increases enhances wound healing rates and hemostatic properties, so chitosan films can be used to control bleeding and wound dressing (62). The microsphere-based drug delivery system allows the drug release to be controlled and specific to the target site by carefully adjusting the various polymeric and pharmaceutical compounds. This type of release system, increases the lifespan of the drug and reaches the required dose of the drug to the target cells (63). It has also been reported in the literature, chitosan microspheres with a higher degree of deacetylation provide stronger antibacterial activity than lower degree deacetylation against Staphylococcus aureus at pH 5.5 (64). The deacetylation reaction does not destroy the chitosan chains, so the reduction in polydispersity can be considered as a degree of increase in deacetylation (65). Chitosan nanoparticles are obtained by various methods such as emulsion, ionic gelation, ionic gel, and coacervation or precipitation, etc (66-68). Along with properties such as biocompatibility, biodegradability, and non-toxicity, nanoparticles can prevent the enzymatic degradation of sensitive drugs in the gastrointestinal tract (69,70). Baltzley et al. (71) studied the probable use of chitosan nanoparticles as an intranasal delivery system to amplify olanzapine systemic bioavailability. They prepared these nanoparticles through ionotropic gelation method. olanzapine-loaded chitosan nanoparticles significantly enhanced systemic absorption with 51±11.2% absolute bioavailability as compared to 28±6.7% after intranasal administration of olanzapine solution. The results showed a suggestion that intranasal administration of olanzapine-loaded chitosan nanoparticles formulation could be an attractive modality for the delivery of olanzapine systemically. Al-Ghananeem et al. (72) studied the possible use of chitosan nanoparticles as an intranasal delivery system to amplify didanosine systemic and brain targeting efficiency. They prepared these nanoparticles through ionotropic gelation method and they studied prepared nanoparticles size, drug loading, and in vitro release. Chitosan nanoparticles displayed an average particle size in the range of 269-382 nm and an average loading capacity ranging from 9.1% to 47.3% with average encapsulation efficiency up to 94.6%. Thus, both the intranasal route of administration and formulation of didanosine in chitosan nanoparticles augmented the delivery of didanosine to cerebrospinal fluid and brain. Smitha et al.(73) developed *O*-carboxymethyl chitosan nanoparticles encapsulated with amidase. The size of the nanoparticles was 300 ± 50 nm. Also, the prepared nanoparticles had an encapsulation efficiency of 55.39%. From this study, they

concluded that the prepared nanoparticles can be used against *S.aureus* infections and chitosan nanoparticles is the most suitable candidate for the oral vaccine delivery system. Pattani et al. (74) studied the immunological effects and membrane interactions of chitosan nanoparticles using nitric oxide production, porcine interleukin-2 gene expression, and lymphocyte proliferation involved in the wound-healing process. The particle size of the developed nanoparticulate system was 373.1 nm with a polydispersity index of 0.696. It was observed that porcine interleukin-2 gene expression was not induced at any of the doses used. However, a statistically significant dose-dependent increase in nitric oxide production was observed at doses above 68.18 µg/mL equivalent to chitosan. Moreover, chitosan nanoparticles showed a statistically significant and dose-dependent lymphocyte proliferation as compared to the control ($P < 0.05$). Bivas-Benita et al. (75) studied the pulmonary delivery of deoxyribonucleic acid (DNA) vaccines against tuberculosis. Chitosan nanoparticles loaded with DNA had an average size of 376±59 nm and a zeta-potential of 21±4mV. The particles had a loading efficiency above 99%. It was shown that the chitosan-DNA formulation was able to induce the maturation of dendritic cells while chitosan solution alone could not, indicating the DNA was released from the particles and able to stimulate dendritic cells. Pulmonary administration of the DNA plasmid incorporated in chitosan nanoparticles was shown to induce increased levels of interferon-gamma secretion compared to pulmonary delivery of plasmid in solution or the more frequently used intramuscular immunization route. They concluded that pulmonary delivery of DNA vaccines may be a preferable delivery route compared to intramuscular immunization. Hosseinzadeh et al. (76) prepared a stimuli-responsive hydrogel nanocomposite via surface reversible addition-fragmentation chain transfer copolymerization. This hydrogel was prepared from acrylic acid and N-isopropyl acrylamide onto chitosan and subsequent in situ synthesis of magnetic Fe_3O_4 nanoparticles. Doxorubicin was then loaded onto this carrier. The Fe_3O_4 magnetic nanoparticles had an average diameter of 15-20 nm. The results showed that the maximum doxorubicin loading efficiency of nanocomposite was 89 % and 82% of total doxorubicin was released from the hydrogel within 2 days. Gholami et al. (77) used chitosan nanoparticles as a dual action carrier for doxorubicin and superparamagnetic iron oxide nanoparticles. They were loaded at different concentrations within poly-L-arginine-chitosan-triphosphate matrix using the ionic gelation method. The results showed nanoparticles size were in the range of 184.33 ± 4.4 nm. Doxorubicin had a burst release at pH 5.5 and a slow release at pH 7.4. In vitro magnetic resonance imaging (MRI) showed a decline in T_2 relaxation times by increasing iron concentration. MRI analysis also confirmed uptake of NPs at the optimum concentration in C6 glioma cells. Contrast efficiencies of the samples showed that the nanoparticles could be utilized as an appropriate MRI contrast agent. Chen et al. (78) investigated the formation and properties of a novel polyelectrolyte complex of drug carrier system for the delivery of doxorubicin, which consists of hyaluronic acid coated hydrophobically modified chitosan. The sizes of nanoparticles were found to be in the range of 280-310 nm. Also, the increase in hyaluronic acid reduced the zeta potentials and the size of the nanoparticles. The results showed that doxorubicin could be easily incorporated into the nanoparticles with encapsulation efficiency (56%) and kept a sustained release manner without burst effect when exposed to phosphate-buffered saline (pH 7.4) at 37°C.

Chitosan is commonly used to deliver drugs such as doxorubicin, methotrexate, gemcitabine, oxytetracycline, carvedilol, gentamicin, ibuprofen, and metformin (52).

2.3. Micelle

Polymeric micelles usually include several block copolymers, a hydrophobic core in which the drug is loaded, and a shell consisting of a dense hydrophilic brush on its surface (79,80). This unique class of amphiphilic polymers with small sizes (10-100 nm) can encapsulate hydrophobic drugs in the core and, along with the circulating system, find the target cells and eventually release the drug (23). The unique properties of micelles include biocompatibility, non-toxicity, small scale, accumulation in target cell, removal from the organism after degradation or dissolution, stability, and high loading capacity (81-83). The most common polymeric micelles used are amphiphilic di-block (hydrophilic-hydrophobic) or tri-block (hydrophilic-hydrophobic-hydrophilic) polymers. Also, extra structures have inclusive

grafting copolymers (hydrophobic-hydrophobic) or ionic (hydrophobic-ionic). Poly(ethylene oxide) (PEO) [also known as poly(ethylene glycol) (PEG)] is usually the most common hydrophilic block in micelles (84,85). PEO properties include hydrophobicity, electrically neutral, non-toxic, and flexible (84). The length of the PEO block usually varies between 1 to 15 kDa, also the PEO coating prolongs their circulation system (85). Usually, the most commonly used for the central core of polyethers include poly(propylene oxide), polyamino acids such as poly(L-histidine), such as dioleoyl (phosphatidylethanolamine), polyesters such as poly(L-lactide) (84,85). In polymer micelles, block copolymers sensitive to pH, temperature, light, and chemical changes are used to release drugs (86-89). Kost et al. (90) studied micelles based on polylactide with β-cyclodextrin core and used it as an effective intracellular drug carrier. The hydrodynamic diameter of nanoparticles measured by dynamic light scattering ranges from 100 to 175 nm. Also, nanoparticles are spherical without visible crack or pores and have narrow dispersity. Doxorubicin loading did not significantly alter the nanoparticle size. Data demonstrated that the micelle/doxorubicin more effectively inhibited the cell proliferation than similar enantiomeric micelles and for the highest concentration of doxorubicin inside the micelles. Muddineti et al. (91) studied a vitamin-E conjugated amphiphilic polymer has been utilized to form a doxorubicin-loaded nano-micellar system. The size of micelles was 141.2 ± 0.78 nm with doxorubicin-loading efficiency as 14.2 ± 0.19%. Micelles exhibited significant cytotoxic action to both the resistant cancer cells. Luo et al. (92) studied the dual pH/redox-responsive mixed polymeric micelles which are self-assembled from poly(ethylene glycol) methyl ether-b-poly(β-amino esters) and poly(ethylene glycol) methyl ether-grafted disulfide-poly(β-amino esters). The particle size was around 115.1 to 160.7 nm. But, after loading doxorubicin, the particle size was approximately 148 nm. The doxorubicin was released due to the swelling and disassembly of nanoparticles triggered by low pH and high glutathione concentrations in tumor cells. The results showed that drug release rate and cumulative release are obviously dependent on pH values and reducing agents. Huang et al. (93) studied the amphiphilic star copolymer pH/reduction stimuli-responsive cross-linked micelles (SCMs) as a smart drug delivery for doxorubicin release. All particles have a spherical morphology and have a size of around 100-180 nm with narrow unimodal distribution (PDI < 0.2). The SCMs owned a low release of doxorubicin in blood circulation and normal tissues while it had a fast release in tumor higher glutathione concentration and/or lower pH value conditions. The values of the thermodynamic parameters at pH 7.4 and at pH 5.0 conditions indicated that the doxorubicin release was endothermic and controlled mainly by the forces of electrostatic interaction. Yao et al. (94) studied the micelles assembled by a matrix metalloproteinase 2, polyethylene glycol, and phosphatidylethanolamine. The micelles were 100 nm in size with a spherical shape and a smooth surface, and the drug-loaded was doxorubicin. The drug encapsulation did not significantly change the micelles' particle size. The results showed that the micelles could inhibit the drug efflux, facilitate cellular uptake and penetration, and increase drugs' tumor targeting and retention, leading to the improved anticancer activity.

Micelles are commonly used to deliver drugs such as doxorubicin, methotrexate, paclitaxel, vinblastine, cisplatin, nystatin, rapamycin, fenofibrate (84,95).

The use of disulfide bonds in amphiphilic block copolymers is very interesting because these bonds are very stable in physiological conditions in the circulating system as well as in extracellular tissues due to a low concentration of reductive glutathione tripeptide (most abundant reducing molecule present in millimolar concentrations in the intracellular compartments), but can rapidly degrade in a highly reductive environment within the cell, and the guest molecule is released (87). Also, disulfides are used in degradable dendrimers and can be used as a mortal bond in the core. In recent years, polysulfides have received much attention in various fields such as gene delivery, drug delivery, rubbers, high contrast materials for magnetic resonance imaging, high performance nanocomposites, solar cells, and lithium batteries (96-99). In addition, due to the dynamic covalent of disulfide bonding, they can be considered in the category of self-healing polymers, which is very important in their other applications such as adhesives, coatings, and rubbers (100-102).

Conclusion

In conclusion, we believe that polymeric carriers are a promising modality for diagnosis and treatment of cancer. However, the development of polymeric-carriers is still in its infancy, but the growing trend of science offers a very successful future. Many of the polymer systems attended in these days are replacing conventional medical platforms due to their main features, such as the lack of side effects and reduced damage to healthy cells in body. The application of external or internal stimuli is highly recommended for cancer treatments. The shift from mono- to dual to multi-stimuli-responsive polymeric materials has progressed the instruction in their usage in delivering medicine with removing the disasters supported by mono and dual responsive materials. Also, many polymeric-carriers have the ability to load multiple drugs simultaneously. These responsive options have this ability to mimic some biological applications and identify at the molecular level.

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مقاله مروری

سرطان و نقش حامل‌های پلیمری در تشخیص و درمان

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چکیده

با پیشرفت روزانه علم و استفاده از علوم مختلف در پزشکی، دستاوردهای جدیدی برای درمان انسان حاصل می‌شود. یکی از علوم پیشگام در این زمینه مهندسی پلیمر است، این ماکرومولکول‌های جادویی می‌توانند به گونه‌ای طراحی شوند که در زمینه‌های مختلفی مورد استفاده قرار گیرند. آنها می‌توانند به عنوان پروتز، حامل دارو، ژن رسانی و غیره مورد استفاده قرار گیرند. در سال‌های اخیر آنها برای تشخیص و درمان سرطان به خدمت پزشکی رسیده‌اند. پلیمرها کاندید خوبی برای انتشار داروهای ضد سرطان هستند. رهایش به موقع، عدم سمیت و زیست تخریب‌پذیری از ویژگی‌های مهم یک حامل است. این خاصیت در بسیاری از پلیمرهای مصنوعی و طبیعی یافت می‌شود و می‌توان با طراحی ساختار آنها برای یک کاربرد منحصر به‌فرد استفاده کرد. این مطالعه به طور خلاصه آمار سرطان در ایالات متحده و ایران را معرفی کرده و چندین حامل پلیمری مانند دندریمر، کیتوسان و مایسل را که در تشخیص و معالجه سرطان استفاده می‌شود را معرفی می‌کند.

کلمات کلیدی: سرطان، پلیمر، دندریمر، کیتوسان، مایسل

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