Shining a Light on Metal and Nonmetal Biomaterials in Colorectal Cancer Therapy: Illuminating New Frontiers

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Abstract

In the ever-evolving landscape of cancer treatment, innovative approaches utilizing biomaterials have made remarkable strides. Among these, metal biomaterials have emerged as promising tools in the fight against cancer. The treatment of colorectal cancer, the second most prevalent cancer, faces challenges due to the presence of confounding variables in the colorectal environment and the lack of effective drug delivery. The use of both types of metallic and non-metallic biomaterials has had extremely hopeful consequences in a variety of cancer therapy approaches. The most used biomaterials in the treatment of cancers have been in the form of nanoparticles or nanocylinders, which are used alone or in combination with anticancer drugs. Hence, the present review tried to provide a snapshot of the applications of biomaterials in cancers with an emphasis on colorectal cancer.

Keywords: Anti-cancer, Colorectal cancer, Biomaterial, Metal, Non-metal

Background

Cancer is a global health problem that has a significant new case and mortality rate annually and causes health and economic losses as well as emotional damage to human society.1 Colorectal cancers are the third most prevalent cancer and have the second highest cancer death rate.2 Exposure to radioactive rays, food preservatives, smoking, genetic background, infectious agents, and chronic inflammation are the key risk factors for colorectal cancer.3 Most of the sciences are looking for methods for the rapid and early detection of cancers as well as their more effective treatments. Henceforth, countless efforts have been made to integrate the sciences using the potential of overlapping disciplines (interdisciplinary) against this deadly disease, and they are still ongoing. The science of materials engineering, especially metallurgy, has specifically dealt with the properties of elements (both metallic and non-metallic) and their behavior in the face of different elements and materials. In this regard, biomaterials, as revolutionary phenomena, created a highly effective bridge between materials engineering and medical sciences and led to amazing advances in diagnostic and therapeutic fields.4 Although there are pieces of evidence of the extremely ancient use of biomaterials, this use has entered a new phase in recent decades.5 Extensive use of orthopedic implants, cardiovascular stents, and the like, increasing the efficiency of diagnostic equipment (imaging and laboratory), and optimizing drug delivery in antimicrobial and anticancer trials have brought very encouraging outcomes.6 In the last case, cancer cells were investigated in in vivo and in vitro environments in contact with various metals (in micro and/or nano size) alone or in combination with other medicinal substances.7 The present review, explored the fascinating applications of metal and non-metal biomaterials in cancer therapy approaches, with a focus on colorectal cancer, highlighting their unique properties and the transformative impact on improving therapeutic outcomes.

The Unique Appeal of Metal Biomaterials (A New Savior)

Metal biomaterials possess a distinctive set of properties that lend themselves to various cancer treatment strategies.8 Their biocompatibility, conductivity, structural integrity, and tunable physicochemical properties make them desirable candidates for use in cancer therapies.8 This section delves into the reasons why metal biomaterials have captured the attention of researchers and clinicians seeking innovative solutions. Indeed, metal particles at a very small scale are known as nanoparticles, and research has shown that various metal elements can exhibit high biocompatibility in biological environments as biomaterials.9 Nano-sized metallic particles such as gold, silver, iron, and the like have been used extensively in trials to enhance drug delivery to living tissues and cells, so that drug delivery by nanoparticles has become more
targeted. The anti-cancer properties of metal elements are in an aura of uncertainty, but they are used directly and indirectly in the treatment of cancers. Photodynamic therapy is a cancer treatment method, in which a specific wavelength is irradiated using light-sensitizing substances (e.g., porphyrin photosensitizers) that can cause the death of targeted cancer cells. Moreover, gold nanoparticles can strongly bind to molecules such as proteins, peptides, antibodies, oligonucleotides, and the like. Investigating the effects of photodynamic therapy on the survival of all types of cancer cells in the presence of gold nanoparticles conjugated with protoporphyrin has been extremely satisfactory. Nanoparticles can more effectively carry medicinal compounds to the target tissue, so this property of metal particles (gold) in nano size can be used for the effective treatment of colorectal cancers. Gold nanoparticles are particularly popular in the applications of photothermal therapy, which is one of the treatment methods for cancer, due to their unique properties such as the absorption and emission of electromagnetic radiation. This treatment strategy uses electromagnetic radiation to produce heat to thermally destroy cancer cells. Accordingly, the cell membrane will be destroyed as a result of hyperthermia. One of the disadvantages of this method is damage to healthy cells that are adjacent to malignant cells; however, metal-based particles for precise targeting cells and tissues have been extremely helpful using biomaterials and material science engineering. Gold particles have high absorption in a wide range of spectra from ultraviolet to infrared, which uses less time and intensity of radiation (laser) during the treatment. Hyperthermia therapy is the emerging treatment procedure against solid tumors, which utilizes the controlled application of heat and seems to be promising as an effective cancer treatment modality. Metal-based materials (e.g., gold nanoparticles) can efficiently convert external energy sources such as near-infrared light into localized heat and selectively damage cancer cells. In the case of various gastrointestinal cancers, especially colorectal, it can be recommended that the use of metal-based particles for local or more targeted treatments can be safer and more efficient. According to Kuppusamy and colleagues’ in vitro study, synthesized gold nanoparticles using aqueous extract exhibited very surprising anticancer effects on human colon carcinoma-116 colon cancer cells. Among ongoing research, the potential of silver as an anticancer agent has emerged as an intriguing avenue. Silver possesses diverse properties that make it an attractive candidate for cancer therapy. Its potent antimicrobial, anti-inflammatory, and wound-healing abilities have long been recognized. However, recent studies have unveiled its remarkable potential as an anticancer agent. Silver displays an array of mechanisms that contribute to its anticancer effect in colorectal cancer. These mechanisms include inhibiting proliferation, triggering cell cycle arrest, inducing apoptosis, suppressing angiogenesis, and modulating crucial signaling pathways. Silver nanoparticles with their unique physicochemical properties have attracted considerable attention as a potent anticancer tool. Their small size, high surface-to-volume ratio, and enhanced cellular uptake allow targeted delivery and interaction with colorectal cancer cells. Silver’s anticancer effect is further amplified in combination with existing treatments. Combinations of silver with chemotherapeutic agents, radiation, or immunotherapies have shown promising results, potentially improving the overall treatment response in colorectal cancer.

Non-metal Biomaterials: Unveiling the Versatility

In the realm of cancer treatment, biomaterials have emerged as powerful allies, offering innovative approaches to combat this formidable disease. While metal biomaterials have garnered considerable attention, non-metal biomaterials have also leaped to the forefront with their unique properties and applications. Non-metal biomaterials encompass an array of materials, including polymers, ceramics, hydrogels, and biocomposites, each one of which possesses distinct properties and functionalities. Non-metal biomaterials have emerged as ideal carriers for controlled drug delivery systems in colorectal cancer treatment. Their ability to encapsulate therapeutic agents protects them from degradation, and releasing them in a controlled manner offers enhanced treatment efficiency and reduced side effects. Non-metal biomaterials play a vital role in tissue engineering approaches for cancer treatment. By providing scaffolds with suitable mechanical properties and biocompatibility, these materials support the regeneration and reconstruction of affected tissues.

Non-metal biomaterials also have demonstrated immense potential in photodynamic therapy, a minimally invasive treatment modality that harnesses light-activated agents to eradicate cancer cells, from photosensitizers embedded in polymeric nanoparticles to bioactive ceramics. Injectable hydrogels, composed of non-metal biomaterials, have emerged as promising vehicles for localized drug delivery and tissue regeneration. The unique properties of hydrogels allow for minimally invasive delivery, on-demand release of therapeutics, and the promotion of tissue repair.

Non-metal biomaterials have the potential for creating bioreponsive drug delivery systems that can be activated or triggered by specific cancer-related cues. By integrating stimuli-responsive polymers, nanoparticles, or implantable devices, these systems can release therapeutic agents in response to tumor-specific signals such as pH, enzymes, or temperature.
Conclusion

While metal and non-metal biomaterials provide remarkable opportunities (e.g., controlled drug delivery capabilities, tissue engineering potential, unique photodynamic and bioresponsive properties, and implantable devices), several challenges need to be addressed. From biocompatibility assessments to long-term stability and clinical translation, the present review highlighted the importance of consistent research, collaboration, and regulatory frameworks to uncover the full potential of non-metal biomaterials in cancer treatment. It also presented an outlook on future possibilities and emerging trends in the field.

Authors’ Contribution

Conceptualization: Neda Khatami.
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References