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Probiotic Bacteria for Targeted Drug Delivery: Potential Applications in Cancer Therapy

Nikita*
M.Sc. in Medical Biotechnology, MDU Rohtak
Email: nikitarana8800@gmail.com

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* Corresponding author

Abstract
Conventional cancer treatments like radiation and chemotherapy frequently fail to meet expectations owing to side effects include systemic toxicity, lack of selectivity, and drug resistance. Targeted medication delivery systems have recently gained attention as a potential way to improve treatment effectiveness while reducing side effects. This research delves at the idea of using probiotic bacteria as a fresh way to deliver drugs to specific areas in cancer treatment. Due to their unique properties, such as their ability to colonise specific environments, interact with the immune system, and be engineered for targeted actions, probiotic bacteria have the potential to enhance drug delivery systems. These bacteria are traditionally known for their beneficial effects on gut health. This paper provides a comprehensive overview of the latest developments in the use of probiotic bacteria to deliver anti-cancer medications to tumour areas. It delves into the various methods of action, such as encapsulation techniques, genetic alterations, and the capacity to target the tumour microenvironment. The article emphasises the benefits of utilising probiotic bacteria, including their compatibility with the body, capacity to control immunological responses, and less systemic toxicity in comparison to traditional medicine delivery methods. On top of that, the article delves into the present status of clinical and preclinical research, highlighting important studies that prove the effectiveness and safety of drug delivery systems based on probiotics in cancer treatment. “The field is viewed in its entirety, including challenges such as regulatory barriers, strain selection, and potential safety concerns. Possible applications of probiotic bacteria in cancer treatment are discussed, such as boosting the efficacy of immunotherapy and chemotherapy drugs. We recommend more studies to look into genetically engineered probiotics, how they interact with cancer cells, and how to evaluate their safety over the long run.

Keywords: Probiotic Bacteria, Targeted Drug Delivery, Cancer Therapy, Drug Delivery Systems, Tumor Targeting, Genetic Engineering, Encapsulation Techniques

Introduction

The treatment of cancer, the biggest killer on a global scale, is fraught with difficulties. For many years, chemotherapy, radiation therapy, and surgical removal of cancerous cells have formed the backbone of cancer treatment. Systemic toxicity, drug resistance, and inadequate specificity are some of the major disadvantages of these approaches, which can cause patients to have negative side effects and a lower quality of life. Targeted medication delivery has emerged as a prominent field in response to these issues; its goal is to maximise therapeutic efficacy while minimising off-target consequences. The goal of developing targeted medication delivery systems is to improve treatment outcomes while decreasing

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collateral damage to healthy tissues by delivering therapeutic molecules directly to tumour locations. The utilisation of probiotic bacteria for targeted medicine delivery is one of the novel avenues that has shown promise among the current investigations. Recently, probiotic bacteria have gained interest for their possible use in medicine delivery, in addition to their well-known positive benefits on immune function and gut health. Because of their adaptability and inherent capacity to engage with the host immune system, these microbes can be designed to transport therapeutic substances to precise locations inside the body. Improved biocompatibility, less systemic toxicity, and the capacity to control immune responses are just a few of the new benefits that make probiotic bacteria a promising candidate for cancer treatment. Genetic engineering to create bacteria with the ability to secrete therapeutic agents in reaction to certain stimuli and encapsulation techniques to safeguard drugs and guarantee their controlled release are two of the many approaches to incorporating probiotic bacteria into drug delivery systems. In addition, when applied to tumours, probiotics can target their specific microenvironment, offering a solution to the problems of medication resistance and inadequate drug penetration that are typical of traditional treatments. This paper's overarching goal is to survey the literature on the subject of probiotic bacteria and their possible uses in cancer treatment through targeted drug delivery. The article delves into the ways in which probiotics can be used to improve the administration of anti-cancer medications, reviews the latest developments in this area, and focusses on important research that have investigated the safety and effectiveness of drug delivery systems based on probiotics. The study also discusses the restrictions and difficulties of this method, including regulatory issues, choosing the right strain, and safety profiles. The purpose of this paper is to highlight the revolutionary potential of probiotic bacteria in cancer treatment by providing new insights into how this approach could improve patient outcomes and revolutionise the delivery of cancer therapies. It does this by presenting a comprehensive analysis of current research and future directions. By delving into this innovative technology in great depth, this publication hopes to add to the continuing conversation about cancer research and medication delivery while laying the groundwork for more studies and potential clinical uses.

Background on Cancer Therapy

Cancer is characterized by the uncontrolled growth and spread of abnormal cells in the body, leading to the formation of tumors and potentially metastasizing to other organs. It is a major global health concern, with the World Health Organization (WHO) estimating that cancer causes nearly 10 million deaths annually, making it the second leading cause of death worldwide after cardiovascular diseases. The increasing incidence of cancer can be attributed to several factors, including aging populations, environmental pollutants, lifestyle choices such as smoking and poor diet, and genetic predispositions. Conventional cancer therapies include chemotherapy, radiotherapy, and surgery. Chemotherapy involves the use of cytotoxic drugs designed to kill rapidly dividing cells, a hallmark of cancer. Although effective in targeting cancer cells, chemotherapy is associated with severe side effects such as nausea, hair loss, and immunosuppression, due to its impact on normal, rapidly dividing cells like those in the gastrointestinal tract and hair follicles. Radiotherapy employs high-energy radiation to damage the DNA of cancer cells, leading to their death. While radiotherapy can be effective for localized tumors, it can also cause damage to surrounding healthy tissues and increase the risk of secondary cancers. Surgery aims to physically remove tumors from the body and is often the treatment of choice for solid tumors that are localized and operable". However, surgery alone may not be sufficient for tumors that have metastasized or are in complex anatomical locations.

These conventional treatments face significant limitations, including the risk of drug resistance, where cancer cells adapt and become less sensitive to treatment over time. Moreover, the systemic nature of

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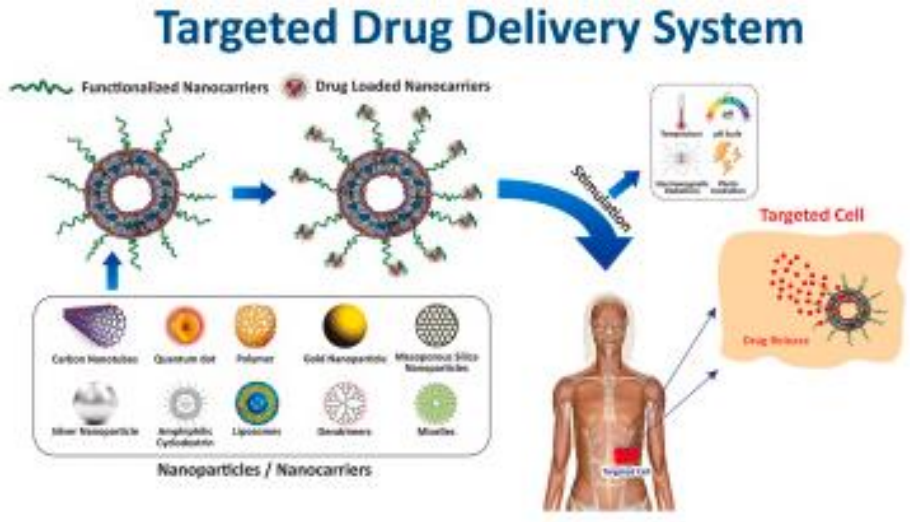
chemotherapy and radiotherapy often leads to adverse effects that can severely impact patients' quality of life. The challenge of achieving complete tumor eradication while preserving healthy tissue highlights the need for more targeted and personalized treatment approaches.

Importance of Targeted Drug Delivery

Targeted drug delivery represents a transformative advancement in cancer therapy, addressing many of the shortcomings associated with conventional treatments. The concept of targeted drug delivery involves designing drug delivery systems that can direct therapeutic agents specifically to cancer cells or tissues while minimizing exposure to healthy cells. This approach is grounded in the principles of molecular targeting, where therapeutic agents are designed to interact with specific biomarkers or receptors that are overexpressed on cancer cells or within the tumor microenvironment.



Source: Targeted drug delivery system

The benefits of targeted drug delivery are manifold. By concentrating the therapeutic agent directly at the tumor site, targeted delivery systems can enhance the drug's efficacy and increase its therapeutic index. This localized approach reduces the systemic dose required, thereby decreasing the risk of adverse side effects that are commonly seen with conventional therapies. Additionally, targeted delivery systems can help overcome issues of drug resistance by ensuring that the drug is delivered in a more effective concentration to the cancer cells. This can lead to improved patient outcomes, including better tumor response rates and reduced incidence of relapse. The development of advanced delivery systems such as nanoparticle-based carriers, antibody-drug conjugates, and gene therapies has significantly advanced the field, offering promising avenues for future cancer treatments.

Review literature

(Cano-Garrido et al., 2015) studied "Lactic acid bacteria: reviewing the potential of a promising delivery live vector for biomedical purposes" and said that Lactic acid bacteria (LAB) have a lengthy history of safe human use in food production and probiotics. Their recent development as microbial cell factories for protein production has led to a secure delivery platform, lower manufacturing costs, and successful disease treatment.

(Deepali et al., 2019) studied "Lactic acid bacteria: reviewing the potential of a promising delivery live vector for biomedical purposes" and said that Lactic acid bacteria (LAB) have a lengthy history of safe

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human use in food production and probiotics. Their recent development as microbial cell factories for protein production has led to a secure delivery platform, lower manufacturing costs, and successful disease treatment.

(Sedighi et al., 2019) studied "Therapeutic bacteria to combat cancer; current advances, challenges, and opportunities" and said that Bacteriotherapy is a novel approach to cancer treatment that has shown promise in regressing tumours and suppressing metastasis in cancer experimental mice.

(Song et al., 2019) studied "Nanotechnology intervention of the microbiome for cancer therapy" and said that Traditional cancer therapies sometimes harm the microbiome. A new way to treat cancer may be possible with the use of nanotechnology, which can regulate interactions on a tiny and molecular size.

(Sawant et al., 2020) studied "Microbes as Medicines: Harnessing the Power of Bacteria in Advancing Cancer Treatment" and said that Conventional cancer treatments sometimes fail to work and are not selective because of drug resistance. Bacteria have shown potential as an anti-cancer medication due to their ability to target tumours through genetic modification. This has resulted in better clinical outcomes and novel treatment options.

(Chung et al., 2021) studied "A synthetic probiotic engineered for colorectal cancer therapy modulates gut microbiota" and said that Taken together, our findings demonstrate that a stable synthetic probiotic including P. pentosaceus and the P8 therapeutic protein can enhance rebiosis and reduce CRC. In addition, it demonstrates that cell-based designer biopharmaceuticals can improve defective microbiota and treat CRC.

(Sachin & Karn, 2021) studied "Microbial Fabricated Nanosystems: Applications in Drug Delivery and Targeting" and said that Scientific inquiry into microbially derived nanosystems for biomedical and drug delivery applications is ongoing. The enhanced metal tolerance of these nanoparticles has potential applications in bioremediation, biomineralisation, and medicinal agents.

(Dicks & Vermeulen, 2022) studied "Do Bacteria Provide an Alternative to Cancer Treatment and What Role Does Lactic Acid Bacteria Play" and said that In 2020, 10 million will succumb to cancer, and by 2030, 21.6 million additional cases will be reported. There are a variety of therapeutic options available, including hormone, immunological, and antibody-based therapies, radiation, chemotherapy, and surgery.

(Mueller et al., 2022) studied "Bacteria-Mediated Modulatory Strategies for Colorectal Cancer Treatment" and said that Colorectal cancer is a prevalent form of cancer that has metastasised to several organs and has become resistant to numerous medications. As a possible selective and non-toxic therapeutic option, researchers are looking into bacteriotherapy, which employs a range of bacterial processes and procedures.

(Ting et al., 2022) studied "Cancer pharmacomicrobiomics: targeting microbiota to optimise cancer therapy outcomes" and said that The gut microbiota is involved in determining the efficacy and adverse effects of cancer treatments, according to a large body of studies. By manipulating their gut microbiota using antibiotics, probiotics, and faecal microbiota transplantation, cancer patients may experience improved treatment outcomes.

(Wei et al., 2022) studied "Recent Advances in Bacteria-Based Cancer Treatment" and said that Anticancer immunotherapy based on bacteria offers excellent and flexible cancer suppression capabilities because to the large number of molecular patterns associated with pathogens. The utilisation of engineered microbes with detoxification and specificity capabilities is critical for efficacy. Constituents of inexperienced bacteria may one day serve as strong theranostic agents.

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(Yuksel et al., 2023) studied "Lung Microbiota: Its Relationship to Respiratory System Diseases and Approaches for Lung-Targeted Probiotic Bacteria Delivery" and said that Several respiratory illnesses, including COVID-19 infection, cystic fibrosis, pneumonia, bronchopulmonary dysplasia, allergy-asthma, influenza, and lung cancer, are explored in this study along with the link between the lungs' microbiota. It goes over how probiotics function, how they are made, and how they could be used in the future for lung-targeted dosing.
(Zong et al., 2023) studied "Bacteria and Bacterial Components as Natural Bio-Nanocarriers for Drug and Gene Delivery Systems in Cancer Therapy" and said that Despite the polyvalent cancer treatments provided by bacteria and bacterial components, problems with biosafety, efficiency, and procedures continue. Combinatorial approaches and nanotechnology hold the key to overcoming these challenges and improving abdominoplastic nanoplatforms.

Introduction to Probiotic Bacteria

Probiotic bacteria are live microorganisms that provide health benefits when administered in adequate amounts. "Commonly found in fermented foods like yogurt and kefir, as well as dietary supplements, probiotics are recognized for their role in maintaining and enhancing gut health. They contribute to a balanced gut microbiota, which is essential for proper digestion, immune function, and prevention of gastrointestinal disorders. Probiotics include strains such as Lactobacillus, Bifidobacterium, and Saccharomyces, each with specific health benefits.
The mechanisms through which probiotics exert their effects are diverse. They produce antimicrobial substances that inhibit the growth of pathogenic bacteria, modulate the immune system to enhance the body's defense mechanisms, and strengthen the gut barrier function to prevent the leakage of harmful substances into the bloodstream. Emerging research has also highlighted the potential of probiotics beyond gut health, exploring their role in various therapeutic applications, including drug delivery systems. Probiotics can be engineered to produce therapeutic proteins, deliver drugs to specific sites within the body, or modulate immune responses to enhance the efficacy of other treatments. Their ability to be tailored for specific functions makes them a promising tool for novel therapeutic strategies.

Probiotic Bacteria in Drug Delivery Systems

The application of probiotic bacteria in drug delivery systems has gained significant interest due to recent advancements in biotechnology. Probiotic bacteria are unique in their ability to colonize specific environments within the body", which can be harnessed for targeted drug delivery. Advances in genetic engineering have enabled the modification of probiotics to express or release therapeutic agents in response to specific stimuli, such as the presence of tumor markers or environmental conditions within the body.

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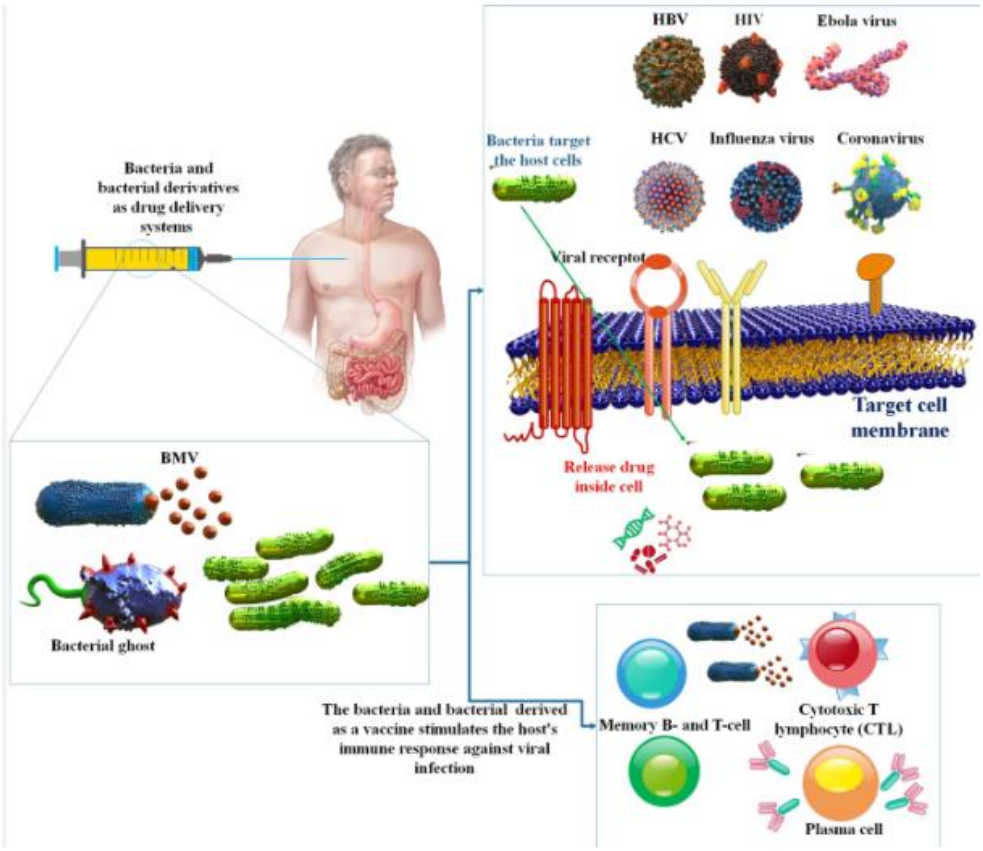

Source: Drug Delivery Systems

One notable approach is the encapsulation of therapeutic agents within probiotic bacteria, which protects the drug from degradation and ensures its controlled release at the target site. Additionally, probiotics can be engineered to enhance their stability and functionality in the body, improving their performance as drug delivery vehicles. The potential advantages of using probiotics in drug delivery systems include improved specificity for targeting tumor cells, reduced systemic toxicity due to localized drug release, and the ability to modulate immune responses to enhance therapeutic outcomes. These properties make probiotic bacteria an attractive option for developing advanced drug delivery systems with applications in various therapeutic areas, including cancer treatment.

Relevance to Cancer Therapy

The integration of probiotic bacteria into cancer therapy offers a novel approach to overcoming some of the key challenges associated with traditional cancer treatments. The use of probiotics for targeted drug delivery addresses issues such as systemic toxicity, poor drug penetration, and drug resistance. By leveraging probiotics' natural ability to colonize specific environments and interact with the host's biological systems, it is possible to develop drug delivery systems that provide localized and sustained therapeutic effects.

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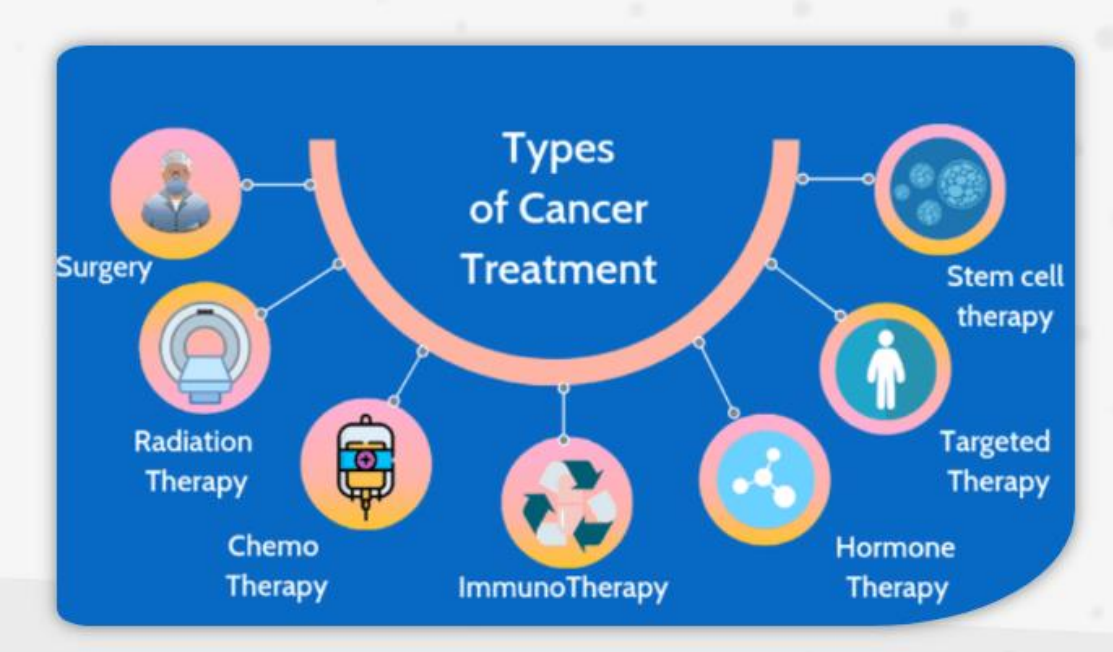

Source: Cancer Therapy

Probiotic bacteria can be engineered to target specific biomarkers or conditions within tumors, enhancing the precision of drug delivery and improving treatment efficacy. This targeted approach not only reduces the collateral damage to healthy tissues but also holds the potential to synergize with existing therapies, such as chemotherapy and immunotherapy, by providing sustained and localized drug release. The use of probiotics in cancer therapy represents a significant advancement in the field, offering the potential for more personalized and effective treatment strategies. As research continues to evolve, the integration of probiotic bacteria into cancer therapy could lead to transformative changes in how cancer is treated, ultimately improving patient outcomes and quality of life.

Cancer and Its Challenges

Cancer, a complex group of diseases characterized by the uncontrolled proliferation of abnormal cells, represents one of the most formidable challenges in modern medicine. Its impact on global health is profound, with millions of new cases and deaths reported annually. The complexity of cancer lies in its heterogeneity, as it can arise in virtually any organ or tissue, leading to a diverse array of tumor types, each with distinct biological behaviors and responses to treatment. Conventional treatment modalities, such as surgery, chemotherapy, and radiotherapy, have made significant strides in managing cancer; however, they are not without limitations. Surgery, while effective for localized tumors, may not be feasible for tumors in critical locations or those that have metastasized. Chemotherapy and radiotherapy, though effective in targeting rapidly dividing cancer cells, often come with severe side effects due to their impact on normal, healthy tissues. These therapies can lead to complications such as immunosuppression, nausea, and secondary cancers, which significantly affect patients' quality of life. Additionally, the development of drug resistance presents a major obstacle, as cancer cells can evolve and become less responsive to treatment over time. This resistance diminishes the efficacy of conventional therapies and complicates treatment regimens. The challenge is further compounded by the need for personalized treatment approaches, as each patient's cancer may respond differently to the same treatment. The heterogeneity of tumors requires tailored strategies to maximize treatment efficacy and minimize adverse effects. Moreover, the high cost and complexity of advanced cancer treatments

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underscore the need for innovative solutions. Addressing these challenges involves exploring novel therapeutic strategies that can enhance the precision and effectiveness of cancer treatment, reduce side effects, and overcome resistance mechanisms. The integration of emerging technologies and targeted approaches promises to transform cancer therapy, offering new hope for improved outcomes and better quality of life for patients.

Role of Probiotic Bacteria in Medicine

Probiotic bacteria, often recognized for their role in maintaining gut health, are emerging as a valuable tool in modern medicine due to their diverse therapeutic potential. These live microorganisms, found in fermented foods and dietary supplements, provide numerous health benefits beyond gastrointestinal health. Probiotics, such as Lactobacillus and Bifidobacterium species, contribute to a balanced microbiota, enhance immune function, and protect against pathogenic infections. Their role in medicine extends to various areas, including the modulation of immune responses, treatment of metabolic disorders, and potential applications in cancer therapy. Probiotics can influence "the immune system by interacting with gut-associated lymphoid tissue (GALT), which plays a critical role in maintaining immune homeostasis. By enhancing the production of anti-inflammatory cytokines and promoting the activity of immune cells, probiotics can help modulate immune responses and reduce inflammation. This immunomodulatory effect has implications for treating autoimmune diseases and managing inflammatory conditions. Additionally, probiotics have been shown to improve metabolic health by influencing gut microbiota composition, which can affect nutrient absorption, metabolism, and weight management. Emerging research is also exploring the use of probiotics in cancer treatment, where their ability to modulate immune responses and deliver therapeutic agents to specific sites holds promise. By engineering probiotics to express or release therapeutic compounds, researchers aim to enhance treatment efficacy and minimize side effects. The potential of probiotics in personalized medicine lies in their ability to be tailored for specific therapeutic applications, providing a versatile and innovative approach to addressing various health challenges.

Innovations in Probiotic-Based Drug Delivery

Recent innovations in probiotic-based drug delivery systems have opened new avenues for enhancing the precision and efficacy of therapeutic interventions. Probiotic bacteria, due to their unique ability to colonize specific sites within the body and interact with biological systems, offer novel strategies for targeted drug delivery. Advances in genetic engineering and biotechnology have enabled the modification of probiotics to express therapeutic proteins or release drugs in response to specific stimuli, such as the presence of tumor markers or environmental conditions within the body. These engineered probiotics can be designed to target and deliver therapeutic agents directly to diseased tissues or organs, improving the efficacy of treatments while reducing systemic toxicity. One significant innovation is the use of probiotics in encapsulating therapeutic agents, which protects the drugs from degradation and ensures their controlled release at the target site". This approach enhances the stability and bioavailability of the therapeutic agents, making them more effective. Additionally, probiotics can be engineered to produce or release drugs in a controlled manner, responding to environmental cues or specific biomarkers associated with disease states. The potential advantages of probiotic-based drug delivery systems include increased specificity for targeting disease sites, reduced side effects due to localized drug release, and the ability to modulate immune responses to enhance therapeutic outcomes. These innovations represent a significant advancement in drug delivery technology, offering new possibilities for treating a range of conditions, including cancer, and improving patient care. As research

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continues to evolve, the integration of probiotic bacteria into drug delivery systems promises to revolutionize therapeutic strategies and provide more effective and personalized treatment options.

Conclusion

In conclusion, the use of probiotic bacteria in targeted drug delivery systems holds significant promise for advancing cancer therapy. By harnessing the unique properties of probiotics—such as their ability to colonize specific environments and their potential for targeted therapeutic delivery—new opportunities emerge to enhance treatment efficacy while minimizing adverse effects. This approach addresses key challenges in conventional cancer treatments, including systemic toxicity, poor drug penetration, and drug resistance. As research progresses, integrating probiotics into cancer therapy could revolutionize treatment strategies, offering more precise, effective, and personalized solutions to improve patient outcomes and overall quality of life.

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