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Advancements in Cancer Theranostics

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Cancer is a major health issue in the world today affecting millions of people worldwide. Despite recent advances in cancer treatments, traditional therapies like chemotherapy and radiation have major negative side effects, including loss of healthy tissue. Cancer theranostics was developed for the main purpose of diagnosing cancer in its early stages through therapeutic and cancer diagnosis. Recently, there have been new advances in cancer theranostics regarding nanotechnology, treatment of breast cancer, and the use of MNO2-based nanoparticles. The use of nanoparticles in cancer therapy has shown promising results, allowing for more precise cancer treatment and improved imaging modalities. Breast cancer, particularly triple-negative breast cancer, is one of the deadliest and most aggressive subtypes, and currently available endocrine therapy is ineffective. Immunotherapy and cancer theranostics can be used together to amplify treatments in patients. With these resources, cancer theranostics development can grow quickly in these coming years and can turn into an amazing resource for cancer patients. The personalization, targeted therapy, reduction in cost, and most importantly its ability to detect cancer early, there is hope for the treatment of cancer in the future.

Introduction

Cancer affects millions of people globally every single day and is one of the main causes of death. As a result, cancer has gained traction in biomedical research as it causes a severe threat to a human's well-being. According to the National Cancer Institute, "In 2022, an estimated 609,360 people will die from cancer in the United States". Over the years, there have been many crucial technological advancements in cancer treatment and diagnosis, however, treatments such as radiation therapy and chemotherapy have severe complications, including hair loss, nausea, lymphedema, nerve damage, and much more. The most detrimental side effect of these therapies is the loss of healthy tissue. Furthermore, recent advances in cancer theranostics promises a new hope in proper and effective cancer treatment.

Cancer theranostics consists of cancer diagnosis and therapy, to put it simply. The idea of theranostics was first proposed by John Funkhouser who served as a CEO of PharmaNetics in the early 2000's. The primary objective of cancer theranostics is to detect cancer in its early stages in a patient to offer precise treatment. It is also considered a targeted therapy, which involves drugs that home in on cancer cells and their molecular passages specifically. Targeted therapies were the building blocks in the development of cancer theranostics. Molecular imaging too, played a big part in the advancement of cancer. Molecular imaging is defined as applying distinct molecules for targeting cancer cells. These molecules can be visualized through using either position emission tomography (PET) or magnetic resonance imaging (MRI). These imaging techniques

enable the efficient and precise detection of cancer.

Targeted therapies consist of medicine that flows through the blood and attaches to a particular area the cancer cells. In contrast to normal targeted therapies, the drugs utilized in cancer theranostics are bound to a radioactive element that exudes radioactivity with the intention of killing cancer cells. What makes cancer theranostics stand out from the rest of the targeted therapies, is that doctors can infer where the drug will end up going. How is this possible? In the diagnostic phase, doctors direct a drug with an isotope that transmits the slightest radiation that is not able to damage cells, but doctors are able to envision where the medicine is stored in the body. The drug during the therapeutic phase contains a therapeutic isotope which secretes radiation so, doctors can see where the drug travels to kill the cancer cells. Thus, meaning that doctors can personalize cancer treatment in a patient pertaining to the genetic profile of the cancer cells. Cancer theranostics has developed greatly and quickly over the years with technological advancements using nanotechnology to transport targeted therapies to cancer cells. Every development in cancer theranostics is bringing doctors close to curing cancer than ever and it is the future.

Recent Progress

Molecular imaging is a medical imaging technique that allows observation, analysis, and quantification of biological activities at molecular and cellular levels in living organisms. It allows the visualization, characterization, and measurement of these processes, without the need for invasive procedures. Specialized imaging agents like radiotracers, fluorescent dyes, and nanoparticles are utilized in molecular imaging to target specific molecules, cells, or tissues of interest for visualization, characterization, and measurement of biological processes at the molecular and cellular levels of living organisms. Molecular imaging offers several benefits, including the capacity to gather insights to the molecular and cellular mechanisms responsible for diseases. This valuable information can assist in the timely detection, diagnosis, and treatment of many medical conditions, such as cardiovascular diseases, neurological disorder, infectious diseases, and cancer. For instance, the technique can detect excessive biomarkers or receptors expressed in cancer cells, which helps identify tumors early and tract the response to treatment. Despite its potential benefits, molecular imaging presents some challenges that need to be addressed. These include the requirement for specialized equipment, the considerable cost of imaging agents, and potential risks related to ionizing radiation. Nonetheless, current research efforts in the field of molecular imaging are focused on overcoming these limitations and advancing the technology's potential applications in clinical practice, with the aim of enhancing patient outcomes.

Nanoparticles (NPs) are utilized as therapeutic or imaging agents to strengthen and regulate biodistribution and diminish the toxicity of drugs. They are also defined by their small size, which is one of their critical features. In the realm of cancer therapy, NPs exhibit numerous characteristics such as high affinity, excellent solubility, high specificity, high thermal stability, and low off-target accumulation. The field of medicine is presently advancing nanotechnology for the purpose of drug delivery, with numerous substances currently being researched for their potential in cancer therapy. Once the toxicology of the drug nanocarrier has been evaluated, solid nanoparticles can be utilized for drug targeting to reach the desired diseased site in the body. The surface of NPs can be conjugated with tumor-specific ligands to achieve active targeting. In a recent study, functionalized nanoparticles were enveloped in cancer cell membranes, resulting in particles that closely mimic the antigenic exterior of the source cancer cells (Siddique and Chow 2022). This approach enabled efficient delivery of immunological adjuvant and membrane-bound tumor-associated antigens to the cancer

cells, promoting an anticancer immune response. The potential of mesoporous silica nanoparticles in theranostic applications is significant, with a diverse range of formulations and demonstrated in vivo efficacy in preclinical models for treating various malignant diseases. A patient diagnosed with oral cancer tends to have a low survival rate. However, research suggests that inhibiting GST, which are proteins that are overactive when a person is diagnosed with cancer, with nanoparticles may be a promising approach to reverse drug resistance to pingyangmycin and carboplatin in oral cancer, leading to significant improvements in treatment outcomes (Siddique and Chow 2022). Overall, recent advancements in functionalized nanoparticle development have enabled more precise cancer therapy and improved imaging modalities. The combination of these modalities with therapeutic applications has led to more accurate patient-specific treatments. Furthermore, the development of new theranostic nanoagents that serve multiple purposes in combination modalities has complemented these efforts.

Theranostics has shown great promise in the treatment of breast cancer. Breast cancer compromises nearly one-third of all cancer diagnoses in women. The traditional classification of breast cancer includes four molecular subtypes: luminal A, HER-2 enriched, luminal B, and triple-negative breast cancer (TNBC). TNBC is characterized by the absence of hormone receptors estrogen receptor (ER) and progesterone receptor (PR) and the human epidermal growth factor receptor 2 (HER-2). Of all the breast cancer subtypes, TNBC is regarded as the deadliest and represents 15% of all breast cancer cases (Choi et. al 2022). Compared to other subtypes, TNBC is recognized as an aggressive subtype with a higher rate of BRCA1 mutation, recurrence, metastasis, and mortality. Due to the absence of receptors, TNBC patients do not benefit from currently available endocrine therapy or anti-HER-2 therapy. Therefore, chemotherapy with taxanes and anthracyclines is still the one systemic treatment option for TNBC.

Another study done regarding TNBC included biocompatible theranostic erythrocyte-derived nanoparticles (EDNs) were advanced and assessed for early discovery and treatment in TNBC. The anti-epidermal growth factor receptor (EGFR) antibody molecules were fused to the outside of EDNS in purpose of targeting TNBCs (iEDNs). Doxorubicin (DOX) was confined in the diagnostic quantum dots (QD) and EDNs then, were integrated in the lipid bilayers of EDNs. (Choi et. al 2022). The outcome of this study was that the DOX encapsulation and QD incorporation does not have impact on the prepared EDNs. However, the QDs had the most success with its integration in the erythrocyte membrane bilayers for tumor bioimaging. The anti-EGFR antibodies on the EDNs were able to provide a more efficient de of anticancer drugs to the quantum dots that are in the EDNs. On an even better note, the iEDNs-DOX had the best results out of the two for anticancer effect in vivo. (Choi et. al 2022). Overall, the anti-EFGR displayed the greatest effectual tumor imaging two days after the injection. The anti-EGFR iEDNs showed the most efficient delivery of DOX and QDs to target tumor issues. Thus, the disclosure pertains to a tumor-targeted anti-cancer theranostic agent derived from erythrocyte plasma membranes that enables target theranosis of cancers.

The last article explains how nanotechnology will take on an essential function in the advancement of breakthrough therapies as the incidence of cancer escalates. MnO2-based nanosystems with multiple configurations (solid/hollow spheres, nanodots, NSs) have currently been actively researched. Furthermore, MnO2's unique physiochemical traits such as its stimuli-responsiveness, ability to react when stimulated with an acid, GSH, and H2O2, and its ability to modify oxygen, supports its implementation for the medical treatment of cancer (Zhu et. al 2020). Due to their ability to develop O2, nanoparticles composed of MnO2 serve as nanoenzymes and create O2, alleviating oxygen shortage in TME and enhancing the

effectiveness of O2-dependent therapies. When MnO2 was utilized as a nanocarrier for the transport of drugs, the capability of MnO2-based nanoparticles to become acid/GSH/H2O2-activatable played a role in stimuli-responsive drug release to avoid initial leakage from the payload and then safely minimize harmful side effects. When applied with the CDT, MnO2 can produce OH via reacting with H2O2 in a catalytic mechanism equivalent to Fenton. The redox response of MnO2 in reducing TME enables the application of T1-weighted MRI in along with the controlled release of drugs and Fenton-like reaction (Choi et. al 2022). MnO2 can be rapidly removed and avoids unnecessary body build-up and long-term toxicity due to the final product Mn2 ions' solubility in water, which expands its potential in cancer therapy. The clinical application of these MnO2 based nanoplatforms remains constrained because of several lingering issues, and the production of MnO2-based nanoparticles was limited to the laboratory level. For example, while Mn2 is easily eradicated, high concentrations of Mn2 are poisonous to normal cells and collect in the brain. As a result, the administration dosage and path need to be the primary objective of the study at hand. Eventually, as the technologies progress swiftly, more and more credible therapies will be developed and made available to clinics. Meaning that, MnO2-based nanoparticles could be one of the most viable platforms.

Discussion

Cancer theranostics and immunotherapy can be used jointly to enhance the outcome of cancer treatments. Recognizing biomarkers on a person's tumor, aides a doctor in determining what drugs can treat cancer the most efficiently. Another name for this method is precision therapy. Furthermore, various types of immunotherapies are used for theranostic agents. Nivoluamb and pembrolizumanb are both immune checkpoint inhibitors that can be utilized to treat and diagnose cancer. The job of these inhibitors is to block specific proteins that subdue the immune system, which then enables the body's immune system to destroy cancer cells efficiently. Some examples of cancer immunotherapies are Tumor-infiltrating lymphocyte (TIL) therapy and Engineered T-cell receptor (TCR) therapy. TIL therapy extracts T cells that have begun attacking a patient's tumor to grow them in a laboratory (Watson 2021). Once the T cells have grown into a sufficient sized batch, they are inserted back into the patient's body to attack the cancer. TIL therapy is special because it is a personalized treatment since T cells are taken from the patient's immune system. However, TIL therapy is not easily accessed to cancer patients because they are only located at specialized cancer centers. TCR therapy accumulates T cells from the blood of the patient and are genetically modified in a laboratory. The purpose of this is for the modified T cells can then search for targets on the surface on the cancer cells to attack (Watson 2021). However just like TIL therapy, it is only in specialized cancer centers since it is still being experimented on. Therefore, using these drugs as a therapeutic and diagnostic tool assists doctors with enhancing treatment outcomes in patients and reducing side effects.

To summarize, cancer theranostics is an extremely promising approach to cancer diagnosis and treatment. Theranostics has the potential to completely transform the field of oncology through facilitating the delivery of personalized and target therapy, allowing early detection and action, conquering drug resistance, and potentially reducing the cost of cancer treatment. There's an excellent probability that as this field of research evolves, increasing numbers of theranostic medicines will be developed and implemented in clinical environments offering millions of cancer patients across the world hope.

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