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Review

Development of Multi-Functional Nanocarriers for Combined Chemo and Photothermal Cancer Therapy

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Abstract:

Cancer is a multifaceted illness that involves several system dysfunctions and aberrant physiological processes. Many tumor targets are the focus of current therapeutic approaches, and nanotechnology has demonstrated promise for cancer therapy. Tumor targeting is thought to be more effective and aggressive using multifunctional nanocarriers. But creating these nanocarriers requires a complex system with the right backbone, effective function integration, optimum modification sites, and easy preparation techniques. Lately, a large number of carefully crafted multifunctional nanocarriers with encouraging medicinal potential have been discovered. With an emphasis on their platform structures with organic or inorganic backbones, functionalization and modification strategies, and application combination strategies involved in creating nano formulations with functional crosstalk, this review offers a thorough understanding and analysis of the multifunctional nanocarriers that are currently being developed.

Keywords: *Multi-Functional Nanocarriers, Cancer, Chemo Therapy, Photothermal, Therapy.*

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1. INTRODUCTION

The development of multi-functional nanocarriers for combined chemo and photothermal cancer therapy represents a significant advancement in the field of oncology [1][2]. These innovative nanocarriers are designed to deliver chemotherapeutic drugs directly to cancer cells while simultaneously enabling photothermal therapy (PTT), which uses light to generate heat and kill cancer cells [3] [4]. This dual approach not only enhances the efficacy of treatment by attacking cancer cells through multiple mechanisms but also minimizes damage to surrounding healthy tissues [5] [6].

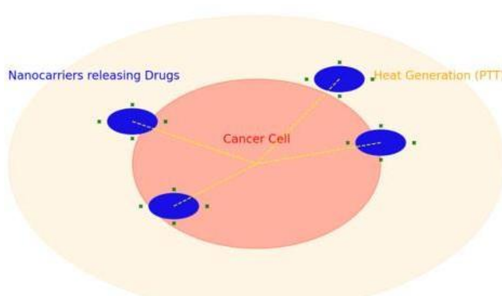

Figure 1: Multi-Functional Nanocarriers for Combined Chemo and Photothermal Cancer Therapy

The integration of chemotherapy and PTT within a single nanocarrier offers a promising strategy to overcome the limitations of traditional cancer treatments, such as drug resistance and non-specific toxicity [7] [8]. By harnessing the unique properties of nanotechnology, such as enhanced permeability and retention effect, targeted delivery, and controlled drug release, multi-functional nanocarriers have the potential to revolutionize cancer therapy, improving patient outcomes and reducing side effects [9] [10].

2. ENHANCED CANCER THERAPY WITH MULTI-FUNCTIONAL NANOCARRIERS

The development of multi-functional nanocarriers marks a significant advancement in cancer therapy by integrating chemotherapy and photothermal therapy (PTT) into a single platform. This dual approach offers targeted delivery, reduced side effects, and improved therapeutic efficacy.

2.1. Multi-Functional Nanocarriers: An Overview

Multi-functional nanocarriers are engineered nanocarriers designed to deliver chemotherapeutic drugs directly to cancer cells while enabling photothermal therapy. These nanocarriers are typically composed of materials that can absorb light and convert it into heat, destroying cancer cells.

2.2. Advantages of Multi-Functional Nanocarriers

1. **Targeted Drug Delivery**
    - Nanocarriers can be designed to specifically target cancer cells, reducing the impact on healthy cells and minimizing side effects.
2. **Combination Therapy**
    - By combining chemotherapy with PTT, nanocarriers can attack cancer cells through multiple mechanisms, enhancing overall treatment efficacy.
3. **Controlled Drug Release**
    - Nanocarriers can be engineered to release drugs in a controlled manner, ensuring sustained therapeutic action.
4. **Enhanced Permeability and Retention (EPR) Effect**
    - Due to their nanoscale size, these carriers can exploit the EPR effect, accumulating more in tumor issues than in normal tissues.

Multi-functional nanocarriers represent a promising frontier in cancer therapy, offering enhanced precision, reduced side effects, and improved therapeutic outcomes. Continued research and development are essential to overcome current challenges and realize the full potential of this innovative approach.

3. BACKBONES AND STRUCTURES OF MULTIFUNCTIONAL NANOCARRIERS

Natural (polymeric, liposomes, lipid-polymer half and half, protein, and peptide) and inorganic (Fe3O4, gold [Au], mesoporous silica, and graphene) and biomimetic (cell layers and exosome) nanoparticle spines are grouped by nanoparticle creation. Due to their flexibility and versatility, these spines are normally changed through covalent or noncovalent means to make multifunctional nanocarriers that can be utilized in cancer therapy. We summarize methods for building multifunctional nanocarriers and focus on methods for modifying organic, inorganic, and biomimetic backbones.

3.1. Organic backbone

PLGA: PLGA, or poly(lactic-co-glycolic) acid, is a combination of the two acids polylactic and polyglycolic.17 The US Food and Drug Administration (FDA) has authorized numerous PLGA-based cancer medications for clinical use, including Lupron DepotR, Sandostatin LarR, and Trelstar, because of its biodegradability and biocompatibility.

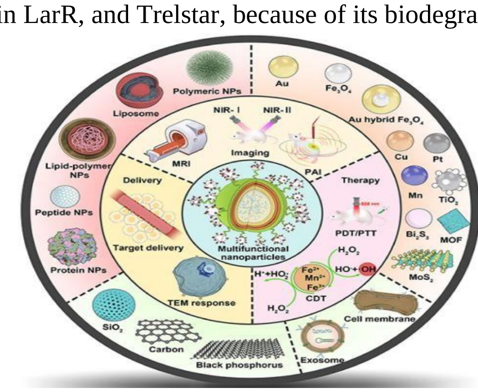

Figure 2: The framework of multifunctional nanoparticle applications and backbone construction techniques

PLGA nanocarriers can be changed to serve multiple purposes due to their hydrophilicity and hydrophobicity, which enable them to form a core-shell structure. Cancer treatment using encapsulation, coating, or covalent modification is possible. To alleviate tumor hypoxia and activate the immune response, water-soluble medicines can be encapsulated. Photochemical agents can be delivered using PLGA-PEG block copolymers, and cancer therapy can be enhanced with coated compounds, both of which serve coating functions.

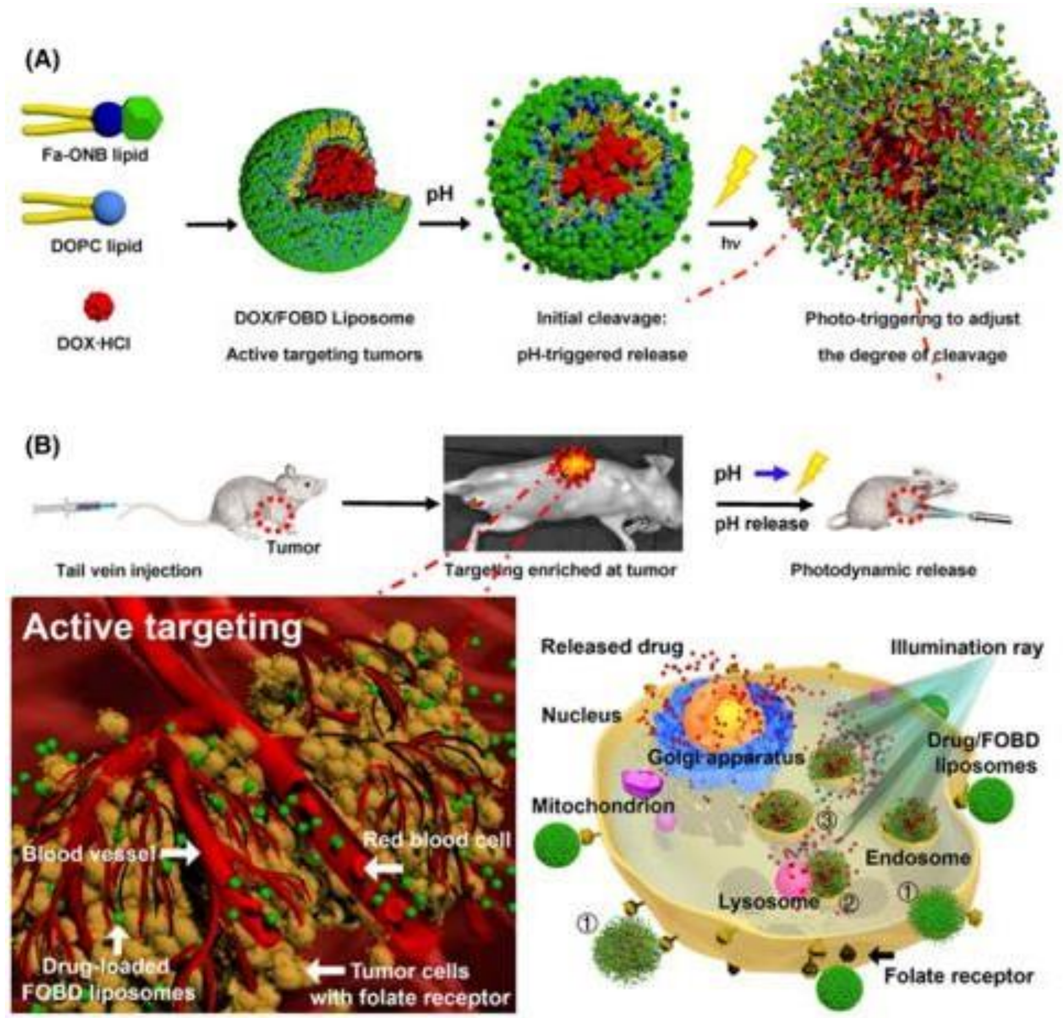

Figure 3: For DOX-targeted cancer therapy, a multifunctional nanoplatform (FOBD) employs folic acid-modified o-nitro-benzyl ester lipid, permitting dual drug release processes via pH and light irradiation.

Nanocarriers, such as RGD–f-PNPs/EPI nanocarriers, have shown therapeutic effects against esophageal cancer and can be monitored using near-infrared fluorescence. Because of their biocompatibility and biodegradability, protein nanocarriers like bovine serum albumin (BSA) and human serum albumin (HSA) have found use in medication administration. These nanocarriers can be modified with amino groups, enhancing chemotherapy effects and inhibiting cell growth [11-32].

3.2. Inorganic backbone

Iron oxide with magnetic properties and minimal toxicity, Fe3O4, has been authorized for use in biomedicine by the US FDA. It is extensively utilized in cancer MRI guiding and targeted drug delivery. Codelivery, physical coating, as well as covalent coupling are multifunctional modification techniques that rely on Fe3O4 nanocarriers. These methods increase the stability of Fe3O4, enable magneto-thermal energy conversion, and improve drug loading or dispersion. Organic materials can also be used to coat the nanocarriers.

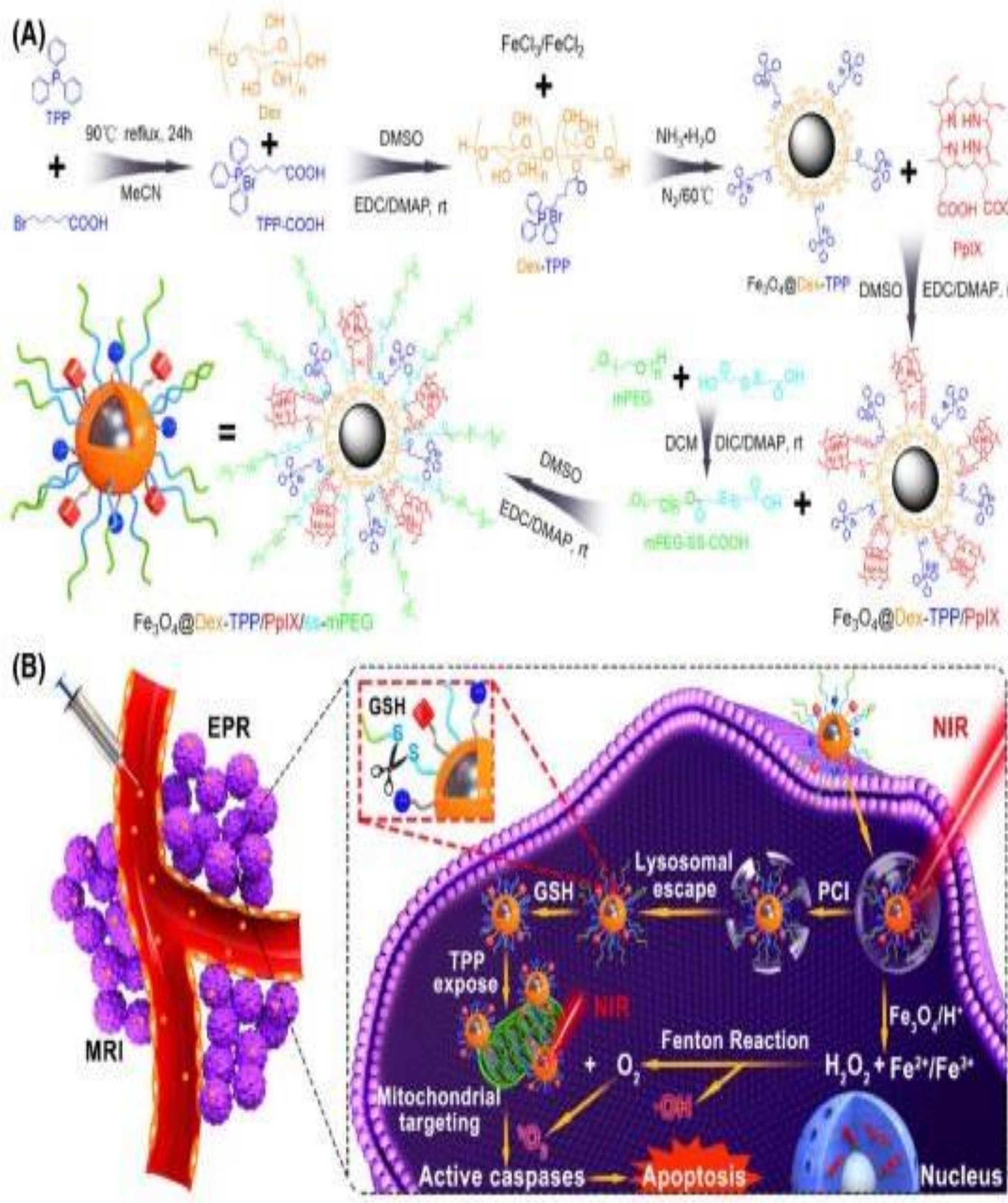

Figure 4: Fe3O4 nanocarriers and protoporphyrin IX delivery photosensitizer for Fenton reaction-assisted photodynamic therapy of cancer, targeting mitochondria and promoting apoptosis under laser irradiation.

Magnetic mesoporous Fe3O4 loaded with PFP enhances thermal ablation and MRI/ ultrasound imaging. Superparamagnetic iron oxide nanocarriers enhance MRI properties and hyperthermia. Au nanocarriers, Cu nanocarriers, and TiO2 nanocarriers offer potential in cancer therapy. Metal-organic frameworks are ideal for drug loading and delivery [33-49].

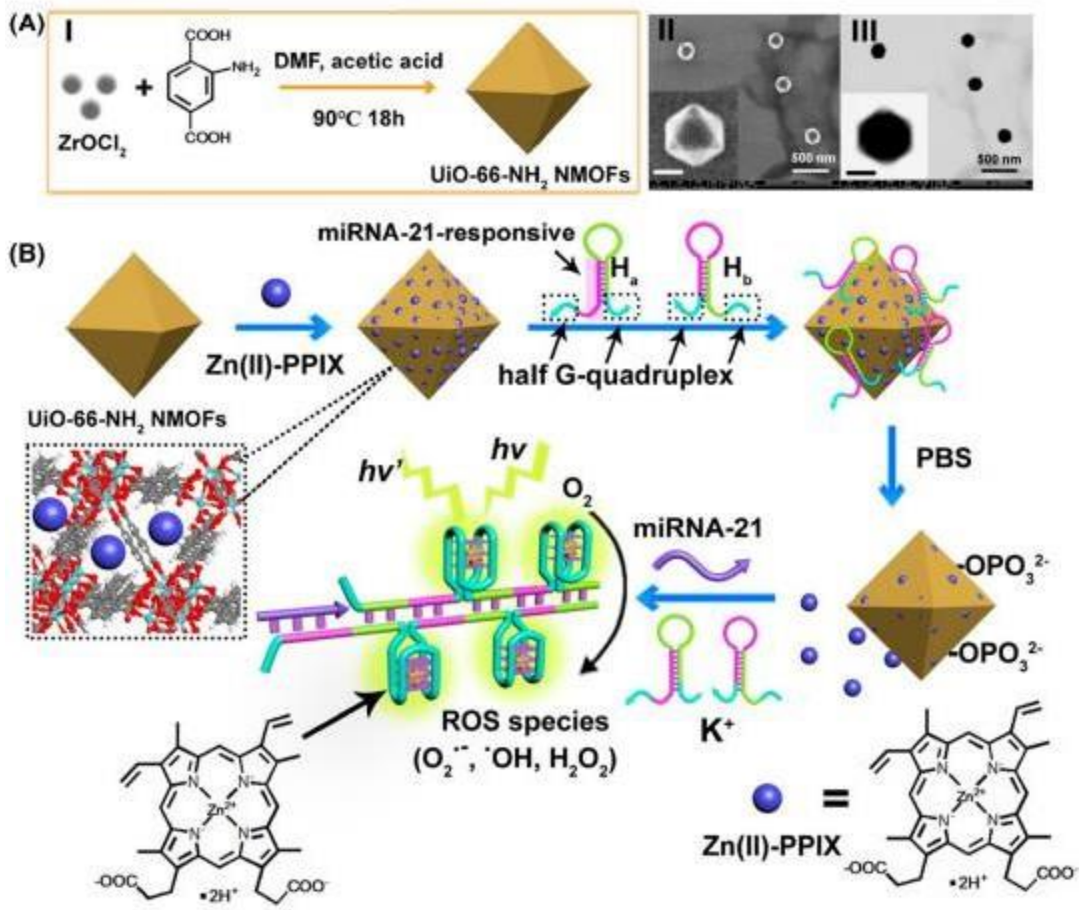

Figure 5: Terephthalic acid in MOF-5 and MOF-74 can modulate immune stimulation signals, improve cancer immunotherapy efficacy, and enhance cancer treatment efficacy with metal nanocarriers, forming multifunctional nanoplatforms.

3.3. Biomimetic backbone

Cell membrane biomimetic nanocarriers are a promising cancer therapy technology that encapsulates nanocarriers or drugs with cell membranes. These phospholipid-based nanocarriers can be coated on drugs or modified by peptides, amines, thiol groups, and carboxyl groups, with exosomes having poor transfection efficiency.

4. APPLICATION STRATEGIES OF MULTIFUNCTIONAL NANOCARRIERS

The treatment of cancer is complicated because cancer cells are very adaptable and unpredictable. Diversified tumor therapy techniques cannot be met by relying on a single functional nanoparticle drug delivery device. The presence and development of tumor cells can be monitored and treated with multifunctional nanocarriers that combine different functions, attaining two or more capacities. These nanocarriers are essential for delivery, therapy, and imaging, enhancing the carrier's application and overcoming obstacles in cancer treatment.

4.1. Multifunction in drug delivery

In the fight against cancers such as lung and glioma, multifunctional nanocarriers engineered to inhibit tumor growth have shown promise. The tumor microenvironment (TME) has aberrant physiological and biochemical features; addressing it with CRISPR-Cas9 systems shows promise. When used in cancer treatment, these nanocarriers improve medication release.

4.2. Multifunction in therapy

Nanocarriers in tumor immunotherapy, photodynamic therapy, photothermal therapy, SDT, and CDT enhance cancer therapy, with research focusing on synergistic approaches for enhanced effectiveness.

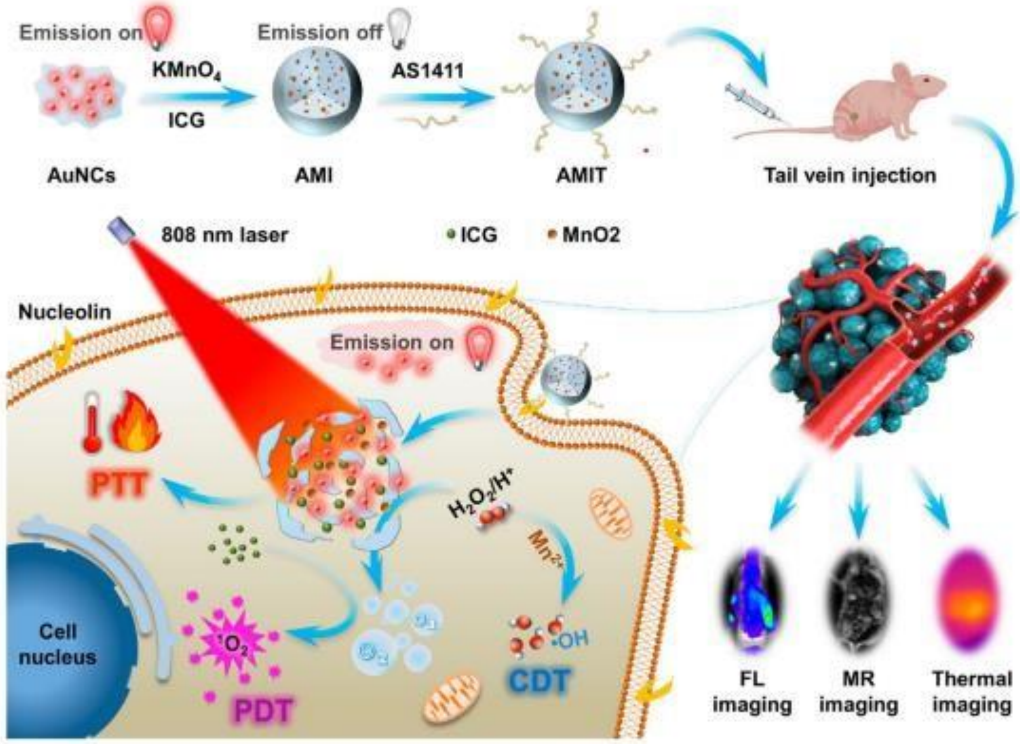

Figure 6: The multifunctional nanoplatform (AMIT) employs gold nanoclusters coated with manganese dioxide for codeliver ICG and aptamer AS141 for targeting and image-guided PDT/CDT/PTT.

4.3. Multifunction in imaging

Magnetic resonance imaging (MRI) changes over the energy of excitation into grayscale pictures by involving the hydrogen protons in tissue to make magnetic minutes and excitation. There are no side effects, it could be useful for diagnosing diseases, and it doesn't require contrast agents. One promising application of multifunctional nanocarriers in cancer treatment is their ability to improve tumor therapy via MRI-guiding. One example is SPIONs.

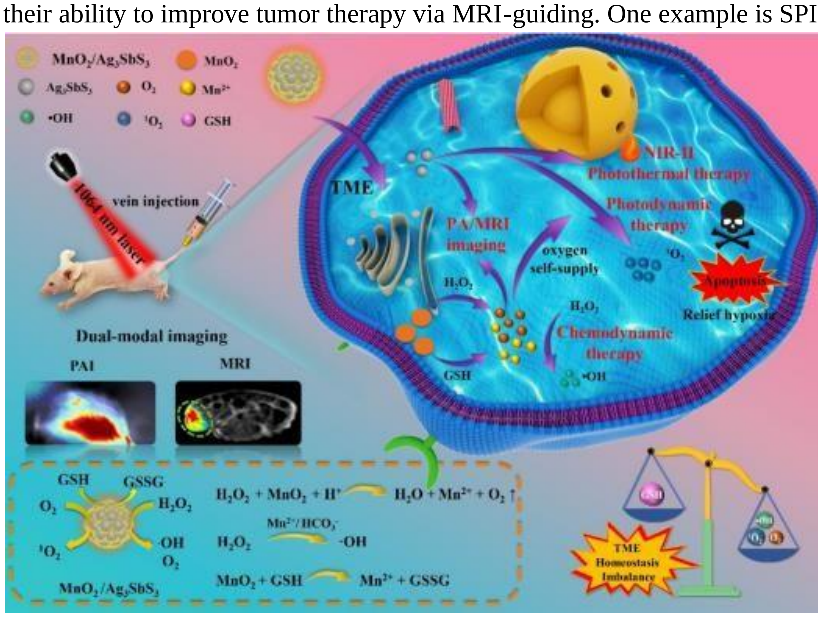

Figure 7: An illustration of a multifunctional nanoplatform (MA) for cancer treatment using PDT/CDT/PTT under a single NIR-II laser, based on manganese dioxide-coated Ag3SbS3 (PTT and PDT agent).

In order to track the effects of drugs and direct cancer treatment, X-ray computed tomography (CT) imaging employs nanocarriers altered with big X-ray attenuation coefficients. For the purpose of clinical research and treatment, multimodal imaging makes use of picture data from various modalities.

5. CONCLUSION

The development of multifunctional nanocarriers for cancer therapy has progressed essentially. They have evaluated how well various spines and approaches for presenting functional gatherings or specialists can be developed. Still, there are problems to be solved, like the lack of docking sites in currently available nanomaterials, the possibility of using natural products like proteins, cells, and microbes, and the possibility of hybrid backbones. Furthermore, semiconducting polymer nanocarriers and carrier-free nanocarriers have a lot of potential for constructive multifunctional nanocarriers. In vivo safety testing and additional development of sophisticated formulations are also required.

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