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Plasma Technology: Unlocking a New Path for Precise Elimination of Cancer Cells

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Abstract: This paper systematically elucidates the application of plasma technology in cancer treatment, including its principles, case studies, comparative advantages over traditional methods, challenges, and countermeasures. Plasma technology targets and eliminates cancer cells with precision through physical, chemical, and immune-regulatory mechanisms, offering high accuracy and low side effects. International applications include plasma scalpels in the United States, combined chemotherapy and low-temperature plasma therapy in Russia, and plasma-targeted capture technology in China. However, plasma technology faces technical hurdles and clinical application barriers, requiring interdisciplinary collaboration and industry-academia-research cooperation to advance its development.

Keywords: Plasma technology; Cancer treatment; Precision; Side effects; Challenges

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1. Introduction

Cancer, a global health challenge, continues to escalate annually. In 2020, approximately 19.29 million new cases were reported globally, with about 9.96 million deaths. The cancer situation in China is particularly severe, with 4.57 million new cases, accounting for one-fourth of the global total. Confronted with the limitations of traditional treatment methods, plasma technology emerges as an innovative therapeutic approach. With its high activity and energy properties, plasma technology precisely disrupts cancer cell structures, induces oxidative stress responses, and inhibits cancer cell proliferation. Compared to traditional methods, plasma technology offers greater specificity, reduced side effects, personalized treatment, ease of operation, and faster recovery. This study aims to explore the application of plasma technology in cancer treatment, analyze its mechanisms and current status, and project future developments to address therapeutic gaps and contribute to precision cancer treatment.

2. Analysis of plasma technology principles

2.1. Material properties of plasma

Plasma can be categorized by temperature into high-temperature plasma and low-temperature plasma, with the latter further divided into cold plasma and thermal plasma. High-temperature plasma, where both electron and heavy particle temperatures exceed 10^6 K, is primarily used for generating nuclear fusion energy. However, the energy of high-temperature plasma is challenging to harness directly for industrial heating. In contrast, low-temperature cold plasma has heavy particle temperatures in the ambient range, while electron temperatures may exceed 10^4 K. Despite this, its energy density is very low, comparable to room-temperature atmospheric gases, rendering it unsuitable as a large-scale industrial energy source. Instead, it is mainly utilized to enhance chemical reactions for surface processing (e.g., etching, coating, doping, cleaning, biomedical applications, and nanomaterial growth and processing), gas treatment (e.g., ozone generation and harmful gas processing), and cold light sources. It is also employed for macroscopic material preparation, such as diamond growth [1].

Plasma, often referred to as the fourth state of matter, differs fundamentally from the traditional three states. It is an ionized gas composed of numerous free electrons, ions, free radicals, and neutral particles. On a microscopic level, its charged particles move at high speeds, interact with each other, and are coupled with external electromagnetic fields, resulting in high activity. These charged particles endow plasma with excellent conductivity, enabling it to rapidly conduct current under an electric field. Despite containing large numbers of charged particles, the positive and negative charge densities are nearly equal, resulting in macroscopic electrical neutrality. This ensures precise and controllable actions.

2.2. Mechanism of plasma generation

Plasma is artificially generated by supplying energy to ionize gases. The heating method increases the kinetic energy of gas molecules through sustained heating, causing electrons to detach from atoms, as seen in tokamak devices that heat plasma to billions of degrees. Electromagnetic excitation methods are more widely applied:

(1) DC glow discharge: Direct current voltage applied between electrodes creates a glow region to generate plasma.

(2) Radiofrequency discharge: Alternating electromagnetic fields ionize gases, allowing precise control over plasma properties, commonly used in cellular experiments.

(3) Microwave discharge: Microwaves interact with gases to produce highly active plasma, enhancing the ability to kill cancer cells.

Plasma parameters influence its performance [2]. Electron temperature affects chemical reaction activity, ion temperature impacts diffusion and transport, plasma density determines action intensity, and the type of gas dictates plasma composition and activity. These parameters must be finely tuned to meet therapeutic requirements.

2.3. Mechanisms of plasma interaction with cancer cells

Plasma eliminates cancer cells through physical, chemical, and immunomodulatory mechanisms, achieving precise destruction.

(1) Physical mechanism: High-energy charged particles in plasma, such as electrons and ions, collide with cancer cells, damaging their membranes and causing intracellular material leakage, osmotic imbalance, and apoptosis or necrosis. Plasma can also penetrate cancer cells, damaging organelles like mitochondria and the endoplasmic reticulum, disrupting energy metabolism and biosynthesis, thereby deactivating cancer cells.

(2) Chemical mechanism: Plasma contains reactive oxygen species (ROS) and reactive nitrogen species (RNS), which are highly redox-active particles. These particles enter cancer cells and react with biomolecules such as nucleic acids, proteins, and lipids. They oxidize DNA bases, causing strand breaks, destabilizing the genome, and hindering DNA replication and transcription. They also interact with protein active groups, altering their conformation and function, disrupting cellular signaling pathways, and activating apoptotic proteins to promote cancer cell apoptosis.

(3) Immunomodulatory mechanism: Plasma treatment alters cancer cell antigen epitopes, making them more recognizable to the immune system and activating innate and adaptive immunity [3]. Macrophages and natural killer (NK) cells engulf cancer cells, releasing cytokines to recruit immune cells, creating a localized immune-activated microenvironment. Additionally, the immune response triggered by plasma has a memory effect, monitoring and suppressing tumor recurrence, thus ensuring long-term cancer treatment and recovery.

3. Application cases of plasma technology in precise cancer cell elimination

3.1. Clinical exploration of plasma surgical tools in the United States

The United States has made significant progress in exploring plasma technology for cancer treatment, achieving innovative results. The Canady Helios Cold Plasma System and surgical tool, developed by US Medical Innovations LLC and the Jerome Canady Research Institute for Advanced Biological and Technological Sciences (JCRI/ABTS), represent a breakthrough after years of research. The system features a low-temperature plasma generator and a pen-like electrosurgical tool that emits blue cold plasma from its tip when activated, opening new possibilities for cancer treatment. Preliminary animal and cellular studies have demonstrated that cold plasma is a highly efficient and selective "cancer killer" [4]. ROS and other toxic molecules produced by the plasma can precisely target tumor cells. Due to the highly oxidative internal environment of cancer cells, ROS induces oxidative stress beyond their threshold, triggering apoptosis, while causing minimal damage to healthy cells.

Previously, three terminally ill patients were treated with the plasma surgical tool under the "compassionate use" principle, successfully clearing residual cancer cells. The research has since received FDA approval to commence Phase I clinical trials involving 20 patients with advanced solid tumors, including pancreatic, ovarian, and breast cancer patients.

3.2. Russia's combination therapy of chemotherapy and cold plasma

Russia has pioneered a novel cancer treatment combining chemotherapy with cold plasma. Researchers tailor the therapy by selecting suitable chemotherapy drugs based on the type of cancer, patient-specific conditions, and disease progression. Concurrently, specialized equipment generates cold plasma, with parameters precisely controlled to ensure activity and efficacy. The two methods then work synergistically to combat cancer [5].

In cellular experiments, this combination therapy has demonstrated impressive anticancer efficacy, successfully targeting over 20 types of cancer cells. The mechanism involves two key aspects:

(1) On the one hand, the ROS and RNS produced by the plasma exert strong oxidative and reductive effects, directly attacking critical components of cancer cells, disrupting metabolic processes, causing genetic information loss, and inducing apoptosis.

(2) On the other hand, the plasma modifies the tumor microenvironment, enhancing the permeability of

chemotherapy drugs, thereby improving efficacy and reducing toxicity.

According to Namik Gusein-Zade, a director at Russia's National Pirogov Medical University, plasma can penetrate several centimeters deep into tissues. For deep tumors, plasma-treated fluids can be injected directly. In some cases, portable plasma generators are sufficient for treatment.

3.3. Plasma-targeted capture technology by Henan Guoshanglian in China

The Henan Guoshanglian Health Management Co., Ltd. has achieved groundbreaking advancements in plasma-targeted capture technology, bringing hope to cancer patients. This technology leverages the natural affinity between boron and cancer cells. By using a specially formulated boron compound beverage as a medium, boron is selectively enriched within cancer cells. Precisely controlled plasma is then applied to target these boron-enriched cells.

The high-energy particles from the plasma interact with boron, releasing immense energy to accurately destroy critical cancer cell structures such as cell membranes, mitochondria, and nucleic acids. This process disrupts the foundations of cancer cell proliferation and survival, efficiently eliminating cancer cells. Since normal cells lack boron, they remain unaffected, preserving the immune system and causing no side effects [6].

Certified by a top-tier inquiry agency under China's Ministry of Science and Technology, Guoshanglian's equipment has achieved a significant breakthrough in the depth of cancer cell eradication, reaching 13 cm—far surpassing similar products in the United States and placing it two generations ahead technologically. This positions the company at the forefront of the field.

Currently, Guoshanglian has developed a comprehensive cancer prevention and treatment system featuring five advanced devices, including cancer cell-clearing capsules and intelligent high-speed radiation cabins. These devices work in coordination to provide precise cancer clearance, functional regulation, and protective functions, offering personalized, one-stop solutions.

4. Advantages of plasma technology compared to traditional cancer treatments

4.1. Precision comparison

Surgical treatment often relies on the surgeon's experience and visual observation, making it challenging to completely remove cancer cells with unclear boundaries or microscopic size, particularly in high-risk procedures such as brain surgeries, which also involve slow recovery. Radiation therapy can destroy cancer cells but may cause damage to normal tissues due to scattered radiation, leading to side effects such as pneumonia and esophagitis. Chemotherapy drugs, lacking specificity, harm healthy cells, resulting in severe side effects and drug resistance [7].

In contrast, plasma technology employs imaging techniques such as CT and MRI for precise tumor localization. Specially designed catheters deliver plasma directly to the tumor site, where the reactive particles preferentially target and destroy cancer cells with minimal impact on normal cells. This greatly enhances the precision and safety of cancer treatment.

4.2. Side effects comparison

Traditional cancer treatments often come with severe side effects. Surgical recovery can be arduous, radiation therapy causes extensive tissue damage, and chemotherapy leads to systemic side effects that significantly impact the patient's quality of life.

Plasma technology, on the other hand, precisely targets cancer cells with minimal damage to normal tissues, resulting in only mild local reactions. Patients do not endure the intense pain and lengthy recovery associated with traditional surgeries. For skin cancers, plasma therapy results in smaller wounds, faster healing, and no inflammatory responses [8]. Additionally, systemic side effects are nearly nonexistent, with no reports of nausea, vomiting, hair loss, or significant immune system disruptions. This significantly improves patients' quality of life, facilitating both treatment and recovery.

4.3. Treatment effectiveness comparison

Plasma ablation technology has demonstrated precision in treating early-stage liver cancer, effectively destroying tumor tissues and inducing rapid tumor necrosis. Post-treatment, patients often exhibit a significant reduction in tumor biomarkers and substantial tumor shrinkage. Patients recover quickly, experiencing less pain in the liver region, improved appetite, and an overall better quality of life.

In terms of long-term outcomes, plasma technology not only eradicates cancer cells but also stimulates the immune system, effectively preventing recurrence. For instance, Russia's combination therapy of chemotherapy and cold plasma has proven to increase the five-year survival rate of lung cancer patients while improving their quality of life ratings [9].

5. Challenges and strategies for plasma technology

5.1. Technical challenges

Despite the availability of various plasma generation methods, such as gas discharge and laser irradiation, achieving stable and efficient generation of plasma with specific parameters inside complex biological environments remains challenging. The requirements for plasma parameters, such as electron and ion temperatures, vary depending on the type of cancer, tumor location, and patient-specific factors. For example, treating deep-seated tumors requires plasma with strong penetration capabilities, necessitating precise control over energy and particle concentration to balance energy attenuation and protect normal tissues. Current technology struggles to meet these demands.

Dose control and safety considerations are also critical. Plasma dosage directly impacts both efficacy and safety. Insufficient doses fail to eradicate cancer cells, while excessive doses induce oxidative stress that damages normal tissues, causing inflammation, fibrosis, and immune imbalance. Establishing precise, standardized dosage protocols is difficult due to variations in tumor characteristics and patient health, which significantly limits clinical adoption [10].

Equipment development and clinical integration also face numerous obstacles. Existing plasma treatment devices are often bulky, and complex, and require specialized personnel for operation and maintenance, making them inaccessible for use in primary healthcare settings. Additionally, technical integration with cancer diagnosis, surgery, and rehabilitation remains problematic. For instance, using plasma technology during surgery requires clear visualization and seamless operation, which remains an urgent issue to resolve and hampers clinical translation.

5.2. Barriers to clinical application

In the clinical trial phase, large-scale, multi-center trials are scarce despite the technology's immense potential. Conducting such trials is costly and demands significant human, financial, and time resources, with challenges at every stage. For example, the Canady Helios low-temperature plasma scalpel trial in the United States required years of preparation before its Phase I clinical trial began, following a decade of foundational research involving tasks like identifying chemical substances and determining tissue penetration properties. These requirements test the limits of research capacity, funding, and patience.

Interdisciplinary collaboration challenges further complicate trials. Communication gaps and inconsistent standards among researchers from different fields hinder the scientific rigor of experiments, delaying the clinical translation of the technology.

The lack of standardization in operation protocols and efficacy evaluation also limits development. Plasma-based cancer treatment currently lacks unified standards for procedures and outcome assessments. Equipment, parameters, and treatment protocols vary across teams and institutions. Critical parameters like optimal dosage, treatment frequency, and duration remain undefined, making it difficult to compare results across studies and objectively evaluate effectiveness. This leaves clinicians without clear guidance and patients with lingering doubts, impeding widespread adoption.

Additionally, physician training and patient awareness are critical issues. Many doctors have only a superficial understanding of emerging plasma technology and lack systematic training, increasing the risk of errors during implementation.

5.3. Strategies for addressing challenges

5.3.1. Interdisciplinary collaboration

Interdisciplinary collaboration is key to overcoming these challenges, as plasma technology spans multiple advanced fields.

(1) Physicists: Develop highly efficient and precise plasma generation devices, optimize electromagnetic fields, and explore new discharge modes to achieve stable parameter control.

(2) Chemists: Analyze chemical reactions to optimize plasma composition, enhance cancer cell targeting, and reduce damage to normal tissues.

(3) Biologists: Investigate molecular biological pathways to provide precise therapeutic targets.

(4) Medical Experts: Integrate this knowledge into diagnostic and therapeutic systems, creating personalized treatment plans to maximize efficacy.

5.3.2. Synergistic innovation between academia, industry, and clinical practice

Collaboration between universities, research institutions, and the private sector is essential for driving innovation and clinical translation.

(1) Academia and research institutions: Increase investment in fundamental research, gather interdisciplinary talent, and solve core challenges.

(2) Industry: Focus on commercializing research outcomes, and improving device portability, usability, and stability while reducing costs.

(3) Healthcare institutions: Collaborate with companies to refine device performance for clinical use.

(4) Government support: Provide incentives, establish funds, and create platforms to foster an ecosystem conducive to plasma technology development and clinical application.

By uniting efforts across disciplines and sectors, plasma technology can overcome its challenges and achieve its potential as a transformative tool in cancer treatment.

6. Conclusion

This study comprehensively explored the application of plasma technology in the precise eradication of cancer cells, analyzing its underlying principles and showcasing its remarkable efficacy in treating various types of cancer through international case studies. Compared with traditional methods, plasma technology demonstrates higher precision and fewer side effects, offering a novel approach to cancer treatment.

Although technical and application challenges remain, advancements in technology and interdisciplinary collaboration present promising prospects for the future development of plasma technology. It is anticipated that the technology will achieve more precise control, integrate with other treatment methods, and become accessible to more medical institutions. Ultimately, plasma technology is poised to become a mainstream cancer treatment method, offering new hope in the fight against cancer.

Disclosure statement

The author declares no conflict of interest.

References

[1] Xia W, Shi K, Wang C, et al., 2023, Plasma Energy Supports China's Industrial Carbon Neutrality. Chinese Journal of Theoretical and Applied Mechanics, 55(12): 2779–2795.

[2] Zhang H, Zhang J, Xu D, et al., 2023, Research Review on Plasma-Activated Water Solutions for Cancer Treatment. Journal of Electrotechnics Technology, 38(S1): 231–246.

[3] Lin S, 2023, Photothermal-photodynamic Synergistic Treatment of Breast Cancer Cells Deep Within Tissue Using Gold Nanorods, dissertation, Fujian Normal University.

[4] Han X, 2023, Construction of a Detection and Drug Delivery Platform for Cancer Biomarkers Based on Hybridization Chain Reaction, dissertation, Beijing University of Chemical Technology.

[5] Wang H, 2023, Molecular Dynamics Simulation Study of Apoptosis in Cancer Cells Under the Synergistic Effects of Plasma Active Particles and Electric Fields, dissertation, Shandong University.

[6] Shi H, Dang L, Lu M, et al., 2023, Risk Analysis and Control of Clinical Use of Plasma Surgical Knife Heads. Medical Equipment and Facilities, 44(6): 80–83.

[7] Chen Y, Ni G, 2022, Development of a High-Voltage Pulse Power Supply for Low-Temperature Plasma Surgical Knives. Power Electronics Technology, 56(1): 99–102.

[8] Xiao Q, Liu D, Gu Y, et al., 2023, Efficacy Analysis of Transoral Low-Temperature Plasma in the Removal of Tonsil Cancer. Medical Research and Trauma Surgery, 36(9): 940–943.

[9] Li C, Jin H, 2023, Low-temperature Plasma-targeted Ablation Combined with Progressive Relaxation Training in Treating Lumbar Disc Herniation and Its Impact on Patients' Sleep Quality. World Journal of Sleep Medicine, 10(5): 960–962 + 967.

[10] Chen C, 2023, Mechanism of Outer Membrane Lysis of Salmonella typhimurium Induced by Cold Plasma, dissertation, South China University of Technology.