Classification and research status of tumor vaccines

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Abstract. As an emerging biological therapy, the classification and research status of tumor vaccines are of great significance for cancer prevention and treatment. This article aims to explore the classification of tumor vaccines and their current research progress. There are two main categories of tumor vaccines: preventive tumor vaccines and therapeutic tumor vaccines. Preventive tumor vaccines aim to prevent the occurrence of tumors by stimulating the body's immune system, while therapeutic tumor vaccines aim to use the immune system to eliminate existing tumor cells. In recent years, significant progress has been made in the research of tumor vaccines. Preventive vaccines such as HPV vaccines have shown significant effects in preventing cervical cancer. In terms of therapeutic vaccines, although still facing many challenges, multiple clinical trials have confirmed that they can enhance the immune system's ability to attack tumor cells, thereby prolonging survival and improving quality of life. Especially tumor vaccines based on mRNA technology are considered a highly promising therapeutic approach due to their unique advantages in activating specific immune responses. Overall, the field of tumor vaccines is still in a rapid development stage, and future research will focus more on their safety, effectiveness, and broad spectrum. With a deeper understanding of tumor immunology and immune escape mechanisms, tumor vaccines are expected to become an important component of cancer treatment.

Keywords: Tumor; Immunotherapy; Tumor Vaccine.

1. Introduction

With the development of modern medicine, people's understanding of cancer is becoming more and more profound, and methods for treating cancer are gradually being explored and extended. Tumor immunotherapy, as a new type of treatment, is increasingly receiving attention from the medical community. As a new type of immunotherapy, the research and application of tumor vaccines have become a hot topic in cancer immunotherapy. This article will review the basic principles of tumor vaccine treatment, classification of tumor vaccines, research status, and research prospects from four aspects.

1.1. Basic Principles of Tumor Vaccine Treatment

Tumor vaccine therapy is an innovative therapy that utilizes the human immune system to combat tumors. The basic principle of this therapy can be divided into four main steps: introducing tumor antigens, activating the immune system, inducing immune responses, and controlling or clearing tumors [1]:

1.1.1. Introduction of Tumor Antigens

The first step in tumor vaccine treatment is to introduce specific tumor antigens into the human body [2]. These antigens are usually specific molecules on the surface of tumor cells or specific proteins inside tumors, which are not present or have extremely low expression levels in normal cells. By introducing these antigens into the human body, we hope to stimulate the immune system to recognize and attack these specific antigens.

1.1.2. Activating the Immune System

When tumor antigens are introduced into the human body, they are captured and processed by antigen-presenting cells in the immune system, such as dendritic cells. These antigen-presenting cells present antigens to T cells, thereby activating T cells and initiating immune responses. In this step,

the immune system begins to recognize and remember these tumor antigens, preparing for the next immune response.

1.1.3. Inducing Immune Response

Once the immune system is activated, it will begin to produce a specific immune response. This includes the production of specific T cells and antibodies that can recognize and attack tumor cells expressing these tumor antigens. In addition, the immune system also produces memory cells, which can quickly initiate an immune response when encountering the same antigen again in the future.

1.1.4. Controlling or Clearing Tumors

The ultimate goal is to control or eliminate tumors through the induction of immune response. When the immune system successfully recognizes and attacks tumor cells, the number and activity of tumor cells will be limited, thereby achieving control over the tumor. In an ideal situation, the immune system is able to eliminate tumor cells and achieve tumor eradication.

In summary, the basic principle of tumor vaccine treatment is to use the body's immune system to fight against tumors. By introducing tumor antigens, activating the immune system, inducing immune responses, and controlling or clearing tumors, tumor vaccine therapy provides a new and promising approach to cancer treatment.

2. Tumor vaccines

2.1. Classification of Tumor Vaccines

Tumor vaccine is a cancer immunotherapy aimed at triggering an immune response against cancer cells. Their goal is to stimulate the immune system to specifically recognize and attack cancer cells without harming healthy cells. The classification of tumor vaccines can be roughly divided into several types based on their source materials and methods of action:

2.1.1. Autologous Tumor Vaccine

Autologous tumor vaccine is a vaccine prepared using the patient's tumor cells, tumor-specific antigens, and other immune regulatory cells and molecules. Its main purpose is to stimulate the body's immune response specific to tumor antigens, achieving the effect of treating tumors and preventing tumor recurrence. This vaccine represents the active and specific immunotherapy methods in the field of tumor biological therapy.

The treatment process of autologous tumor vaccines usually includes steps such as vaccine preparation, vaccine introduction into the body, DC cell phagocytosis of antigens, antigen presentation to T cells, activation of cytotoxic T cells, killing of tumor cells, ideal tumor antigen recognition, and clearance of tumor small residues. Through these steps, autologous tumor vaccines can induce the immune system to specifically attack tumor cells, thereby controlling or clearing the tumor [3].

However, although autologous tumor vaccines have certain therapeutic effects, they cannot completely cure tumors. Meanwhile, the effectiveness of this treatment method also varies depending on the patient and medication. Therefore, when using autologous tumor vaccines to treat tumors, it is necessary to comprehensively consider the specific situation of the patient and the advice of the doctor to develop an appropriate treatment plan.

2.1.2. Allogeneic Tumor Vaccine

Allogenetic tumor vaccine is prepared using tumor cells or tumor antigen substances from different individuals. The purpose of this vaccine is to stimulate the body's specific immune response to attack and eliminate tumor cells.

Compared to autologous tumor vaccines, allogeneic tumor vaccines have some potential advantages. Firstly, it can utilize the immune systems of different individuals to recognize and attack tumor cells, thereby enhancing the intensity and breadth of the immune response [4]. Secondly,

allogeneic tumor vaccines can overcome the possible immunosuppressive states in autologous tumor vaccines, as tumor cells or antigenic substances from different individuals may have different immunogenicity.

However, there are also some challenges and limitations to allogeneic tumor vaccines. Firstly, differences in the immune system between individuals may lead to inconsistent and unstable immune responses. Secondly, more stringent preparation and quality control standards may be required for allogeneic tumor vaccines to ensure their safety and efficacy.

2.1.3. Peptide and Protein Vaccines

Peptide and protein vaccines are two different types of vaccines that differ in vaccine preparation and immune mechanisms.

Peptide vaccines use specific peptide segments as antigens to prevent the occurrence of diseases by stimulating the body's immune response. These peptides typically originate from key components of pathogens, such as specific proteins of viruses or bacteria. By injecting these peptide segments into the human body, the immune system recognizes and produces corresponding antibodies, enabling rapid clearance of pathogens in the event of infection [5]. Peptide vaccines have high specificity and safety, as antibodies generated by them can only target specific pathogen peptide segments and do not cause damage to other tissues in the human body.

Protein vaccines use intact pathogen proteins or protein fragments as antigens to prevent diseases by stimulating the body's immune response. These proteins typically originate from the surface or interior of pathogens and can bind to host cell receptors and enter cells for immune activation. Protein vaccines can stimulate the body to produce various immune responses, including humoral and cellular immunity, thereby providing more comprehensive protection. However, protein vaccines may pose certain safety risks as they may trigger allergic reactions or other adverse reactions.

Overall, peptide and protein vaccines use antigens to stimulate the body's immune response to prevent the occurrence of diseases. They differ in vaccine preparation and immune mechanisms, but both have important application value.

2.1.4. Gene Vaccines

DNA and RNA vaccines are the two main types of genetic vaccines, both of which use partial genes of the virus itself to stimulate immune responses and achieve the goal of disease prevention. Their working principle is to carry the genetic instructions of the host cell to produce antigens, transmit this information to the cells, and produce the required proteins, so that the immune system will react to these proteins. Once the body encounters this protein again, the immune system will fight against it and produce immune protection.

However, there are some differences in the operation of DNA and RNA vaccines. When using DNA vaccines, the genetic information of the virus is transmitted to another molecule called messenger RNA (mRNA). This means that RNA or mRNA vaccines take one step less than DNA vaccines. mRNA enters cells and is converted into proteins, which are substances that organisms could detect and induce immune responses.

In addition, DNA vaccines transmit information through a small electrical pulse, which actually pushes the information into the cell. Its advantage is that this vaccine is very stable at higher temperatures.

Overall, both DNA and RNA vaccines utilize the genes of viruses to stimulate immune responses, but they differ in the process of achieving this goal. Their main difference lies in the way information is transmitted and its stability.

DNA vaccines involve injecting genetically engineered DNA, which encodes cancer-specific antigens (substances recognized by the immune system as foreign substances). The cells in the human body absorb this DNA, produce antigens, and trigger immune responses.

2.1.5. Virus Vector Vaccine

It is a vaccine that uses a virus as a carrier to deliver tumor related antigens into human cells, in order to stimulate the body to produce an anti-tumor immune response. This vaccine aims to utilize the efficient infectivity and antigen presentation system of the virus to enhance the immune system's ability to recognize and attack tumor cells, thereby achieving the goal of preventing and treating tumors.

The working principle of tumor virus vector vaccines is to insert genes encoding tumor related antigens into the virus vector, so that the virus can express these antigens when infecting cells. After the vaccine is injected into the human body, the viral vector enters the cells and expresses antigens, stimulating the body to produce a specific immune response against these antigens [7]. These immune responses include T cell-mediated cellular immunity and antibody mediated humoral immunity, which can work together to attack tumor cells.

Compared with other types of tumor vaccines, tumor virus vector vaccines have some unique advantages. Firstly, viral vectors have the ability to efficiently infect cells, delivering antigens directly into the cells, enhancing the intensity and specificity of immune responses. Secondly, viral vectors can stimulate various immune responses, including cellular and humoral immunity, thereby providing comprehensive anti-tumor protection [8-10]. In addition, tumor virus vector vaccines also have the advantages of simple preparation and low cost.

However, tumor virus vector vaccines also face some challenges and limitations. Firstly, selecting the appropriate viral vector is crucial, as the immunogenicity and safety of different viruses vary. Secondly, the design of tumor virus vector vaccines needs to target specific tumor antigens, so their applicability to different types of tumors may vary. In addition, the clinical application of tumor virus vector vaccines also needs to consider issues such as safety, efficacy, and immunogenicity.

At present, research on tumor virus vector vaccines is still in the preclinical or clinical trial stage and has not been widely applied. In the future, with in-depth research on tumor immunology and virus vector technology, tumor virus vector vaccines are expected to provide new effective means for tumor prevention and treatment.

2.1.6. Dendritic Cell Vaccine

Dendritic cell (DC) vaccine is an emerging biological therapy for malignant tumors in recent years, which has received increasing attention and recognition from oncologists. DC vaccines are mainly based on dendritic cells in the human immune defense system, utilizing their powerful antigen presentation function to induce and enhance immune responses, thereby achieving the goal of treating tumors.

Dendritic cells are important members of the human immune defense system, named after the many branching protrusions that extend outward from their cells and are known as the "sentinels" of the immune system. They have a powerful antigen presentation function, which can capture, process, and present antigens to T cells, thereby initiating immune responses [11].

In the treatment process of DC vaccines, modern high-tech biotechnology is first used to collect peripheral blood from tumor patients and induce the cultivation of a large number of dendritic cells in a short period in vitro. Then, these dendritic cells will be equipped with immune cells that the patient does not have themselves, which can accurately "target" and kill cancer cells.

In addition, DC vaccines can also induce immune memory in patients, enabling them to achieve long-term anti-cancer effects. This immune memory can help the patient's immune system maintain its ability to recognize and attack tumor cells for a long time, effectively preventing tumor recurrence.

Overall, DC vaccines are an innovative treatment method that utilizes and enhances the body's own immune system to combat tumors. However, although DC vaccines have certain therapeutic effects, they cannot completely cure tumors. Therefore, when using DC vaccines to treat tumors, it is necessary to comprehensively consider the specific situation of the patient and the advice of the doctor to develop an appropriate treatment plan.

2.2. Current Research Status of Tumor Vaccines

The research on tumor vaccines is currently in a rapid development stage. Although there is no widely used tumor vaccine, multiple clinical trials and studies have shown that tumor vaccines have enormous potential in preventing and treating tumors.

2.2.1. Research Progress in Preventive Tumor Vaccines

Significant progress has been made in the research of preventive tumor vaccines in recent years. Among them, the research on using dendritic cells (DCs) as vaccine delivery systems has received much attention. Dendritic cells are used to load and present tumor related antigens, thereby stimulating the body to produce specific immune responses and preventing the occurrence of tumors [12]. Researchers extract dendritic cells from patients, culture and activate them in vitro, load them with tumor related antigens, and then inject these dendritic cells back into the patient's body, thereby stimulating the body's immune system to recognize and attack tumors.

In addition to dendritic cell vaccines, other types of preventive tumor vaccines are also being studied. For example, preventive tumor vaccines based on viral vectors use viral vectors to introduce tumor related antigens into the body, stimulating the body to produce an immune response. In addition, some preventive tumor vaccines based on synthetic peptides, recombinant proteins, etc. are also being studied.

In terms of clinical trials, some preventive tumor vaccines have already entered the clinical trial stage. For example, a preventive tumor vaccine based on HPV (human papillomavirus) has been widely used to prevent the occurrence of cervical cancer. In addition, there are also some preventive vaccines against other types of tumors in clinical trials, such as lung cancer, breast cancer, etc. [13].

However, research on preventive tumor vaccines still faces some challenges and limitations. Firstly, tumors have a high degree of heterogeneity and complexity, and the antigen characteristics and immunogenicity of different tumors vary greatly. Therefore, personalized vaccine design and preparation are needed for specific tumor types. Secondly, clinical trials of preventive tumor vaccines require long-term follow-up and large-scale research to verify their safety and efficacy. In addition, the production cost and technical difficulty of preventive tumor vaccines are also high, requiring further technological innovation and optimization.

2.2.2. Research Progress in Therapeutic Tumor Vaccines

The research on therapeutic tumor vaccines has also made significant progress, providing new treatment options for cancer patients. The main purpose of therapeutic tumor vaccines is to attack and eliminate existing tumor cells by activating the body's immune system. The following are some research progress on therapeutic tumor vaccines:

2.2.3. mRNA Based Therapeutic Tumor Vaccine

In recent years, mRNA based therapeutic tumor vaccines have received much attention. For example, the mRNA tumor vaccine mRNA-4157, jointly developed by Moderna and Merck, achieved the primary endpoint in the phase 2b clinical trial of Keytruda in the treatment of melanoma. This vaccine uses mRNA tumor vaccine and PD-1 antibody as adjuvant therapy for postoperative recurrence prevention. Studies have shown that compared to PD-1 antibody monotherapy, combination therapy can reduce the risk of recurrence or death by 44%. This lays the foundation for the mRNA tumor vaccine to enter phase 3 clinical trials and expand to other cancer species [13].

2.2.4. Dendritic Cell Based Therapeutic Vaccine

Dendritic cell vaccines also play an important role in therapeutic tumor vaccines. Researchers extract dendritic cells from patients, culture and activate them in vitro, load them with tumor related antigens, and then inject these dendritic cells back into the patient's body, thereby stimulating the body's immune system to recognize and attack tumors. This method has been tested in clinical trials of various tumors and has achieved certain therapeutic effects.

2.2.5. Limitation of Therapeutic Vaccine

In addition to mRNA tumor vaccines and dendritic cell vaccines, other types of therapeutic tumor vaccines are also being studied. For example, vaccines based on whole cells or cell lysates, vaccines based on viral vectors, etc. These vaccines have been clinically tested in different types and conditions of tumors, providing cancer patients with more treatment options.

However, research on therapeutic tumor vaccines still faces some challenges and limitations. Firstly, tumors have a high degree of heterogeneity and complexity, and there are significant differences in tumor types and conditions among different patients. Therefore, personalized vaccine design and preparation are needed for specific situations. Secondly, the efficacy and safety of therapeutic tumor vaccines need to be rigorously validated through clinical trials. In addition, the production cost and technical difficulty of therapeutic tumor vaccines are also high, requiring further technological innovation and optimization.

Overall, although research on therapeutic tumor vaccines has made some progress, more research and practice are still needed to verify their efficacy and safety. In the future, with the deepening of immunology and oncology research, as well as the continuous innovation and optimization of technology, the therapeutic tumor vaccines are expected to provide new treatment options for cancer patients and new means of preventing the occurrence of tumors.

2.3. Research Prospects of Tumor Vaccines

With the continuous progress of science and technology and the deepening development of immunology, the research and application of tumor vaccines will achieve more breakthroughs and achievements. Here are some prospects for tumor vaccine research:

2.3.1. Development of Personalized Tumor Vaccines

Tumors have high heterogeneity and complexity, and there are significant differences in tumor types and conditions among different patients. Therefore, future research on tumor vaccines will focus more on personalized treatment, designing and preparing personalized tumor vaccines based on the specific conditions of patients to improve treatment effectiveness and safety [14].

2.3.2. Development of New Tumor Vaccines

At present, various types of tumor vaccines have entered the clinical trial stage, such as mRNA tumor vaccines, dendritic cell vaccines, etc. In the future, with the continuous development of immunology and molecular biology technologies, it is expected that more new types of tumor vaccines will emerge, providing more treatment options for cancer patients [14].

2.3.3. Exploration of Combination Therapy

The treatment of tumors usually requires a combination of multiple methods to achieve the best therapeutic effect. Future research on tumor vaccines will focus more on the combined use of other treatment methods, such as immune checkpoint inhibitors, chemotherapy drugs, etc., to improve treatment efficacy and reduce side effects.

2.3.4. Expansion of the Application of Cancer Vaccines

At present, tumor vaccines are mainly used for the treatment and prevention of tumors. In the future, with the deepening of research, the application fields of tumor vaccines are expected to be expanded, such as for early diagnosis of tumors, disease monitoring, etc.

2.3.5. Technological Innovation and Optimization

The production cost and technical difficulty of tumor vaccines are high, and further technological innovation and optimization are needed. In the future, with the continuous progress of biotechnology and process optimization, it is expected to reduce the production cost of tumor vaccines, improve production efficiency, and make them more widely used in clinical practice.

In summary, research on tumor vaccines has broad development prospects and potential in the future. With the continuous progress of science and technology and the deepening development of

immunology, it is believed that tumor vaccines will play a greater role in tumor treatment and prevention, bringing better treatment effects and quality of life to cancer patients.

3. Summary

As a promising therapeutic way, the tumor vaccine has achieved great progress recently. By stimulating the immune response, the tumor vaccine could eliminate the tumor cells and establish long-term protection in human bodies. According to its components, the tumor vaccine could be divided into autologous tumor vaccine, allogeneic tumor vaccine, peptide and protein vaccine, gene vaccine, virus vector vaccine and dendritic cell vaccine. Each of these could activate the immune system and initiate tumor clearance. However, owing to the tumor heterogeneity, tumor vaccines with higher efficiency and specificity are still under development. Nowadays, the advancement of tumor vaccines focuses much more on tumor vaccine based combination therapy and personalized tumor vaccine.

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