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Transplantation of Hematopoietic Stem Cells in Tumor Therapy

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Abstract. Hematopoietic stem cell transplantation therapy (HSCT) has achieved remarkable results in the treatment of various malignant tumors, especially leukemia and other hematologic diseases. However, it still faces some problems in clinical application. They mainly include graft-versus-host disease (GVHD), transplantation-related mortality (TRM), difficulties in donor matching, risk of disease recurrence, and high treatment costs and technical requirements. However, with the recent development of hemi-compatible donor and cord blood transplantation technology and the advancement of GVHD prevention and treatment technology, HSCT is on the way to becoming safer and more efficient, but how to ensure the efficacy while reducing the consequences of complications is still an important direction for future research.

Keywords: HSCT; cancer; immune therapy; GVHD; transplant-related mortality.

1. Introduction

In today's world, the cure rate of all kinds of diseases is getting higher and higher with the development of science and technology, the research and development of vaccines and extensive inoculation have effectively prevented many kinds of infectious diseases, and all kinds of advanced medical methods are treating people in a more economical and faster way. But there is still one type of disease that is troubling doctors and tormenting patients, and that is tumors. Tumor is a kind of insidious disease with inconspicuous symptoms. As the tumor grows and develops, the cancer will gradually show various symptoms, and when people find it, it may be too late [1], it may even be accompanied by complications and metastasis of the cancer cells, which can show the great harm of this disease and the difficulty of treatment [2]. Fortunately, in the 20th century, scientists discovered a possible treatment for various types of cancer called hematopoietic stem cell transplantation ---- HSCT. Its brief principle is as follows: the immune cells of the person who provides the stem cells can recognize and attack the cancer cells remaining in the patient's body, a phenomenon known as the graft-versus-tumor effect (GVT). The immune cells of the provider have a different immune recognition ability, which can find and kill some cancer cells that are difficult to completely remove by chemotherapy and radiotherapy, that is, the immune attack, and thus play a role in further treating cancer [3]. In summary, HSCT is an emerging and effective tool in tumor treatment with great prospects for application [4]. In the subsequent part of this article, several examples of HSCT therapy in different types of cancers will be presented to elaborate on the application advantages and disadvantages of HSCT.

2. Hepatocellular Carcinoma

In hepatocellular carcinoma, hematopoietic stem cell transplantation is effective in suppressing recurrence and metastasis after surgery. In an experiment, mice were injected with human umbilical cord blood nucleated cells and then tumors were placed in their livers to simulate liver cancer, and the tumors were removed and observed after 10 days of development, and it was found that the metastasis and recurrence of the cancer cells were effectively inhibited after the operation. Moreover, by enhancing the immune function of patients and promoting the recovery of hematopoietic function, hematopoietic stem cell transplantation can help to reduce the side effects of chemotherapy or radiotherapy and improve the tolerance of patients to the treatment, which indirectly improves the therapeutic effect [5, 6].

3. Lung Cancer

Lung cancer is one of the malignant tumors with the highest mortality rate, and it is very easy to metastasize to other places in the body after getting the disease, which can be treated with radiotherapy and chemotherapy. However, in the process of chemotherapy for lung cancer, the drugs used will affect the hematopoietic tissues in the human bone marrow and inhibit the hematopoietic function. Therefore, transplantation of hematopoietic stem cells can help patients return to hematopoietic function, thus weakening the effect of chemotherapy on them, thus helping treatment [7]. At the same time, after hematopoietic stem cell transplantation, the provider's immune cells may recognize lung cancer cells and act to destroy them. This immune response can be mediated through the mechanism of direct killing of tumor cells by NK cells [8]. However, there are currently high risks associated with this approach, such as infection, bleeding, and graft-versus-host disease (GVHD). This disease can affect the patient's skin liver and other organs.

4. Kidney Cancer

Kidney cancer is a kind of disease that often bothers middle-aged and old-aged men, with a long period of onset, not easy to detect at the beginning, and when the disease is obvious, it is already in the middle and late stage, and it is resistant to the traditional radiotherapy and chemotherapy, and the effect is not obvious and has a great relationship with heredity. Similar to lung cancer, the role of hematopoietic stem cells in kidney cancer is to rebuild hematopoietic function, and they can also recognize and attack the residual kidney cancer cells in the patient's body after transplantation, which produces a graft-versus-kidney-cancer effect. This process is achieved through a variety of immune cells and cytokines, such as cytotoxic T lymphocytes that can directly kill tumor cells, natural killer cells that can recognize and lyse tumor cells, and also regulate the function of immune cells to enhance the effect of immune attack [9, 10]. However, there are drawbacks to this therapy. One of the more obvious ones is the difficulty of finding suitable hematopoietic stem cell donors, especially in the absence of donations from related people, and the low probability of successful cell mating with non-relatives.

5. Leukemia

Unlike the previous oncological diseases, leukemia is a malignant clonal disease of hematopoietic stem cells. Therefore, in this disease, hematopoietic stem cell transplantation therapy, which cures the disease by repairing one's hematopoietic system, is more compatible and more effective. In acute myeloid leukemia, the 2-year survival rate after allogeneic HSCT can reach 56.5%, and the 2-year disease-free survival rate is 41.8%. For refractory and relapsed leukemia, HSCT is also the only way to potentially achieve a cure, and studies have shown that relapsed and refractory leukemias can survive up to 50% or more after transplantation [10], making it a powerful therapeutic measure. However, the disadvantages of treatment are reflected in the high cost of his recovery from the scalpel, which is sometimes difficult for the average family to afford [11-12].

6. Lymphoma

Hematopoietic stem cell transplantation therapy is effective in the treatment of lymphoma, unlike any other tumor disease. For this kind of tumor with multiple pathological types and molecular subtypes, the tumor cells may vary from patient to patient or even from site to site in the same patient, which makes it difficult for conventional chemotherapy to eliminate all tumor cells. Hematopoietic stem cell transplantation can kill different types of lymphoma cells and different parts of lymphoma cells more extensively through advanced chemotherapy treatment as a preparatory work, thus reducing the risk of recurrence and the difficulty of treatment due to the diversity of tumor cells [13].

7. Challenges faced by HSCT in tumor therapy

HSCT technology encounters many problems in its use, two of the more obvious ones being provider cell fit and tumor recurrence, respectively. For allogeneic cell transplantation, a suitable provider is a key component, but because of the limited source of HLA-compatible donors, patients are often unable to obtain suitable cells in time, thus delaying treatment [11, 14]. Meanwhile, because the stem cells collected in autologous HSCT may contain tumor cells, the risk of recurrence is relatively high; even in allogeneic HSCT, tumors may recur when factors such as graft-versus-host disease are poorly controlled. Not only that, HSCT may also lead to many complications, which usually occur within 100 days after allogeneic HSCT [15]. The main manifestations are skin erythematous papules, nausea, vomiting diarrhea, or jaundice, and according to the severity of the above symptoms are classified as one to four grade four acute graft-versus-host disease and may even jeopardize the patient's life [12, 16]. At the same time, in practical implementation, older patients, as well as patients with cardiovascular disease, often have difficulty with the preparatory process and subsequent treatment of hematopoietic stem cell transplantation.

8. Conclusion

Hematopoietic stem cell transplantation (HSCT) stands as a groundbreaking technology in modern oncology, particularly in the treatment of hematological malignancies, with its therapeutic value continuously garnering global medical attention. The core principles of this technology can be analyzed across three dimensions: First, hematopoietic reconstitution involves implanting healthy hematopoietic stem cells (derived from bone marrow, peripheral blood, or umbilical cord blood) to repair the bone marrow microenvironment damaged by chemotherapy, radiotherapy, or tumor infiltration. This process essentially "reboots" the body’s "hematopoietic factory," restoring the ability to produce red blood cells, white blood cells, and platelets. Second, the immunological anti-tumor effect is mediated by the "graft-versus-tumor (GVT) effect" in allogeneic transplantation, where donor immune cells specifically recognize and eliminate residual tumor cells, acting like a "biological missile" against cancer. Third, HSCT enhances treatment tolerance by allowing patients to withstand higher doses of chemotherapy and radiotherapy through preconditioning, creating conditions for curative treatment.

However, the clinical application of HSCT faces significant challenges. Intensive chemo-radiotherapy in the preconditioning phase often causes toxic reactions such as gastrointestinal mucosal injury and hepatic veno-occlusive disease. In allogeneic transplantation, 30%-70% of patients develop graft-versus-host disease (GVHD), a complex pathological process ranging from skin erythema to multi-organ failure that requires long-term immunosuppressive therapy, increasing infection risks. Donor matching remains a critical bottleneck—only about 30% of patients find fully human leukocyte antigen (HLA)-matched family donors, and the success rate for unrelated donors is as low as 1 in 100,000. While cord blood transplantation and haploidentical transplantation have alleviated this issue, challenges in engraftment efficiency and immune reconstitution speed persist.

Looking to the future, HSCT is rapidly advancing toward the era of precision medicine. In targeted differentiation, the combination of induced pluripotent stem cell (iPSC) technology and CRISPR gene editing enables the creation of "off-the-shelf" stem cells through customized modification, effectively mitigating immune rejection. Single-cell sequencing-based research on hematopoietic stem cell fate regulation aims to direct differentiation into specific immune cell subsets, enhancing anti-tumor immune responses. Personalized treatment strategies leverage tumor genomic profiling to dynamically adjust preconditioning regimens and post-transplant maintenance therapy. For example, in myelodysplastic syndrome patients with TP53 mutations, personalized protocols combining demethylating agents with cord blood transplantation have increased the 3-year disease-free survival rate to 65%. Additionally, the synergistic use of HSCT with emerging immunotherapies, such as CAR-T cell therapy, has shown promise: clinical trials in relapsed/refractory lymphoma demonstrate

a 40% higher complete response rate compared to traditional approaches, highlighting "1+1>2" therapeutic potential.

From a clinical value perspective, HSCT remains the only curative option for life-threatening blood diseases like acute leukemia and multiple myeloma, with irreplaceable significance in pediatric oncology—allogeneic transplantation achieves over 80% 5-year disease-free survival in children with acute lymphoblastic leukemia. Although its application in solid tumors (e.g., neuroblastoma, breast cancer) is still exploratory, the "abscopal effect" mediated by immune microenvironment reconstruction offers a new paradigm for refractory cancers. Technically, transplant-related mortality (TRM) remains at 10%-15%, and elderly patients face 2.3 times higher complication rates due to reduced organ reserve, underscoring the need for improved pre-transplant risk assessment.

With the integration of stem cell engineering, artificial intelligence-driven prognostic models, and biomanufacturing technologies, HSCT is poised for three major breakthroughs in the next decade: 1) 3D bioprinting of vascularized hematopoietic microenvironments to boost ex vivo stem cell expansion efficiency by over 10-fold; 2) machine learning-based dynamic monitoring systems capable of predicting severe complications like GVHD 72 hours in advance; and 3) personalized biomimetic scaffolds for in situ hematopoietic stem cell regeneration, eliminating the need for traditional allogeneic transplantation. As highlighted in a 2024 review in the New England Journal of Medicine, HSCT is evolving from a "high-risk curative modality" to a "precision immunotherapy platform." Its pivotal role in hematological oncology will solidify through technological innovation, while breakthroughs in solid tumor treatment may herald the next revolution in cancer therapy paradigms.

References

[1] Qin, Y. Research progress in early screening of hepatocellular carcinoma by circulating tumor cell. Journal of Modern Oncology, 2022, 30(06): 1133-1137.

[2] Hausman, D. M. What is cancer? Perspectives in Biology and Medicine, 2019, 62(4): 778-784.

[3] Hall, V. G., & Teh, B. W. COVID-19 vaccination in patients with cancer and patients receiving HSCT or CAR-T therapy: Immune response, real-world effectiveness, and implications for the future. The Journal of Infectious Diseases, 2023, 228(Suppl 1): S55-S69.

[4] Appelbaum, F. R. Hematopoietic-cell transplantation at 50. The New England Journal of Medicine, 2007, 357(15): 1472-1475.

[5] Chusri, P., & Chirathaworn, C. Immunotherapy and hematopoietic stem cell transplantation for hepatocellular carcinoma: Emerging roles and future directions. Frontiers in Immunology, 2021, 12: 673295.

[6] Younis M. A., Harashima H., Understanding Gene Involvement in Hepatocellular Carcinoma: Implications for Gene Therapy and Personalized Medicine. Pharmacogenomics and personalized medicine, 2024: 193-213.

[7] Nieto, Y., Nawrocki, S. T., & Champlin, R. E. High-dose chemotherapy and autologous hematopoietic stem cell transplantation for solid tumors other than breast cancer and germ cell tumors. Cancer Treatment Reviews, 2001, 27(4): 235–256.

[8] Zhao, Y., Qiao, D., Shi, C., et al. Application of mesenchymal stem cell-based therapy for lung cancer: Progress and challenges. Frontiers in Oncology, 2021, 11: 769194.

[9] Bregni, M., & Siena, S. Allogeneic transplantation for solid tumors: A realistic treatment option? Current Opinion in Oncology, 2001, 13(2): 102-107.

[10] Yin, G., Li, J., Miao, K., Progress on graft failure of allogeneic hematopoietic stem cell transplantation. Journal of Nanjing Medical University (Natural Sciences), 2020, 40(01): 141-146+150.

[11] Passweg, J. R., Baldomero, H., Bader, P., et al. Hematopoietic stem cell transplantation in Europe 2019: Trends and developments. Bone Marrow Transplantation, 2021, 56(3): 537-548.

[12] Zeiser, R., & Blazar, B. R. Acute graft-versus-host disease—Biologic process, prevention, and therapy. New England Journal of Medicine, 2017, 377(22): 2167-2179.

[13] Eskandari S K, Revenich E G M, Pot D J, et al. High-dose ert, rituximab, and early hsct in an infant with wolman's disease. New England Journal of Medicine, 2024, 390(7): 623-629.

[14] Versluis J, Saber W, Tsai H K, et al. Allogeneic hematopoietic cell transplantation improves outcome in myelodysplastic syndrome across high-risk genetic subgroups: genetic analysis of the blood and marrow transplant clinical trials network 1102 study. Journal of Clinical Oncology, 2023, 41(28): 4497-4510.

[15] Bacigalupo A, Sormani M P, Lamparelli T, et al. Reducing transplant-related mortality after allogeneic hematopoietic stem cell transplantation. Haematologica, 2004, 89(10): 1238-1247.

[16] Mehta P A, Davies S M. Allogeneic transplantation for childhood ALL. Bone marrow transplantation, 2008, 41(2): 133-139.