Review

Cancer Biology

A Perspective Review of Cancer Therapy (Part II)
Adoptive Cell Transfer, Metabolic Therapy, and Artificial Intelligence

Alberto Pajuelo*
University of Valencia, Av. de Blasco Ibáñez, 13, El Pla del Real, 46010 València, Valencia, Spain
*: All correspondence should be sent to: Dr. Alberto Pajuelo.
Author's Contact: Alberto Pajuelo, Ph.D., E-mail: alberto.pajuelo@hotmail.com
DOI: https://doi.org/10.15354/si.23.re838
Funding: No funding source declared.
COI: The author declares no competing interest.

In recent years, there has been significant advancement in cancer therapy, with the emergence of novel and inventive methods that provide hope to patients. An advanced approach is adoptive cell transfer, which utilizes the immune system's potential by modifying T cells to identify and eliminate cancer cells. The implementation of this individualized method has demonstrated encouraging effects across different cancer types, resulting in enhanced prognoses for numerous individuals. Metabolic therapy has emerged as a possible treatment technique, alongside adoptive cell transfer. This therapeutic method seeks to interrupt the growth and survival of cancer cells by specifically targeting their abnormal metabolism. Moreover, artificial intelligence (AI) is transforming cancer care by assisting in the identification of diseases, forecasting the likely course of illness, and devising treatment strategies. Artificial intelligence algorithms employ extensive data analysis to identify patterns and anomalies that may not be readily apparent to human specialists in isolation. Oncologists can enhance patient outcomes and reduce unwanted effects by integrating adoptive cell transfer, metabolic therapy, and AI technologies to provide personalized treatments.

Keywords: Cancer; Adoptive Cell Transfer; Metabolic Therapy; Artificial Intelligence; Outcomes

Science Insights, 2023 December 31; Vol. 43, No. 6, pp.1167-1177.

EVERY year, cancer is responsible for the loss of millions of lives, making it one of the most fatal diseases around. Despite this, advancements in medical research have made it possible to develop ground-breaking treatments that have the potential to alleviate the symptoms of this terrible condition. Among the most cutting-edge techniques are adoptive cell transfer, metabolic therapy, and artificial intelligence. These methods target cancer from a variety of angles, offering hope for improved outcomes and, ultimately, a resolution to the disease.

Adoptive cell transfer (ACT) is an innovative cancer therapy that utilizes the immune system's capabilities to combat cancerous cells (1). This therapeutic approach entails the retrieval of immune cells, primarily T cells, from the patient's own body. Subsequently, these cells undergo genetic modification, undergo expansion within the laboratory, and are subsequently reintroduced into the patient's bloodstream. The altered T cells

can subsequently selectively identify and eradicate cancerous cells with enhanced efficiency. ACT has demonstrated exceptional efficacy in the treatment of specific cancer types, such as leukemia and melanoma, with significant response rates and even achieving complete remission in certain individuals (2). The potential of ACT rests in its capacity to personalize and augment the patient's immune response, resulting in more precise and efficient eradication of cancer.

Metabolic treatment is a novel strategy that aims to modify the metabolic conditions inside cancer cells in order to impede their proliferation and viability. Cancer cells rely on unique metabolic pathways to support their fast proliferation and survival. Scientists are investigating methods to disrupt these pathways by changing the metabolism of cancer cells (3). For example, certain studies have demonstrated that withholding glucose, which is the main source of energy for cancer cells, can impede their proliferation (4). Furthermore, the survival of cancer cells can be hindered by specifically targeting key enzymes involved in their metabolism (5). Metabolic therapy has a distinct chance to deprive cancer cells of the necessary resources for their growth, offering a promising pathway for innovative treatment approaches.

The discipline of oncology is being transformed by artificial intelligence (AI), which is facilitating personalized and effective cancer treatment. AI algorithms have the capability to evaluate extensive quantities of data, such as genomic profiles, medical imaging, and patient records (6). By identifying patterns and making predictions, these algorithms can aid physicians in making precise diagnoses and treatment decisions. Through the integration of machine learning and deep learning algorithms, AI has the capability to identify subtle biomarkers that could potentially signify the presence of cancer in its early stages (7). This early detection enables timely intervention and has the potential to improve patient outcomes. AI can enhance treatment planning by accurately forecasting the effectiveness of various medicines based on certain patient attributes. By adopting a personalized approach, patients are provided with treatment alternatives that are specifically matched to their individual needs, hence enhancing the overall efficacy of cancer treatments (8).

It is vital to do additional research and clinical studies in order to thoroughly determine the efficacy of adoptive cell transfer, metabolic treatment, and artificial intelligence in the fight against cancer. Although each of these approaches has specific advantages, additional research and clinical studies are required. Nevertheless, they have a significant potential to revolutionize the field of cancer therapy and to encourage optimism in individuals who have been confronted with this debilitating condition. The incorporation of these innovative strategies, in conjunction with conventional treatments like chemotherapy and radiation therapy, has the potential to develop a comprehensive approach, which could finally lead to the complete elimination of cancer. We are getting closer to the time when cancer will no longer be a life-threatening prognosis and will instead become a state that can be controlled and treated. This is because researchers are consistently making huge improvements in these domains.

Adoptive Cell Transfer

Tumor-Infiltrating Lymphocytes

Tumor-infiltrating lymphocytes (TILs) are immune cells found in the tumor microenvironment that are essential for the body's anti-cancer defense mechanism (9). TILs consist mostly of T cells, B cells, and natural killer cells. The presence of TILs is frequently linked to a more favorable prognosis in individuals with cancer.

TILs are a type of immune cell that has effectively penetrated the tumor tissue, establishing direct interaction with cancer cells. These cells can be distinguished using numerous methods, such as immunohistochemistry or flow cytometry, which aid in differentiating them from non-infiltrating lymphocytes seen in the adjacent healthy tissue (10). The quantity and composition of TILs can exhibit variability between different cancer kinds and stages, as well as within the same tumor.

The primary role of TILs is to identify and eradicate cancerous cells. T lymphocytes play a crucial role in this mechanism, as they have the ability to directly eliminate malignant cells or secrete cytokines to stimulate other immune cells. In contrast, B cells have the ability to generate antibodies that specifically recognize tumor antigens. Natural killer cells exhibit potent cytotoxicity towards cancer cells that exhibit diminished expression of major histocompatibility complex (MHC) molecules, rendering them particularly efficacious against malignancies with downregulated MHC molecules (11).

TILs in tumor tissues have been linked to a more favorable prognosis and an enhanced therapeutic response. Multiple studies have demonstrated that an increased concentration of TILs is linked to improved overall survival rates in different forms of cancer, such as melanoma, ovarian cancer, and colorectal cancer (12-14). These findings indicate that the immune response facilitated by TILs is essential for regulating tumor proliferation and metastasis. TILs might be utilized for therapeutic objectives. Adoptive T cell therapy entails the extraction of TILs from the patient's tumor tissue, their subsequent cultivation in a laboratory setting, and their subsequent reintroduction into the patient. This method has demonstrated encouraging outcomes in the treatment of melanoma and other types of solid malignancies. An alternative strategy entails specifically targeting immunological checkpoints, which are molecules responsible for regulating the response of T cells, such as PD-1 and CTLA-4, using immune checkpoint inhibitors. These inhibitors facilitate the expression of the anti-tumor properties of TILs, leading to enhanced patient outcomes.

Although TILs have the potential to be effective in combating cancer, they encounter various obstacles inside the tumor microenvironment. Cancer cells can employ tactics to avoid immune responses mediated by TILs by increasing the expression of chemicals that suppress the immune system or by releasing cytokines that hinder immunological activity (15). Moreover, the tumor microenvironment might exhibit immunosuppressive properties, characterized by the presence of regulatory T cells and myeloid-derived suppressor cells that hinder the activation and cytotoxic function of TILs.

However, ongoing research endeavors persist in illuminating the intricate relationships between TILs and malignancies. Gaining insight into the processes governing TIL behavior in the tumor microenvironment can pave the way for the creation of

innovative immunotherapies and approaches to bolster anti-tumor immune responses (16). Furthermore, current research endeavors to discover prognostic biomarkers that can aid in the identification of individuals who are most inclined to derive advantages from TIL-based treatments.

TILs are a type of immune cell that penetrate tumor tissues and have a crucial function in the body's immunological defense against cancer. TILs comprise T cells, B cells, and natural killer cells that specifically identify and eliminate cancer cells. TILs in tumor tissues are linked to enhanced patient outcomes. Utilizing the capabilities of TILs for therapeutic applications, such as adoptive cell therapy and immune checkpoint inhibitors, holds great potential for enhancing patient outcomes (17). Nevertheless, the immunosuppressive conditions inside the tumor microenvironment present obstacles to the efficacy of TIL-mediated anti-tumor reactions. Additional investigation is required to surmount these barriers and formulate more efficient immunotherapeutic approaches centered around TILs.

Natural Killer Cell Therapy

Natural killer (NK) cells are a subset of leukocytes that constitute an integral component of the body's innate immune response. Unlike other immune cells, NK cells do not necessitate particular detection of cancer cells in order to engage in their destruction. This distinctive attribute makes them a perfect choice for cancer treatment.

NK cell therapy entails the extraction of these cells from either the patient's own immune system or a donor, followed by their isolation and amplification in a laboratory, and subsequently reintroducing them into the patient's body (18). The objective is to augment the patient's immune response against cancer cells and enhance overall therapy outcomes. This therapy can serve as a viable substitute or supplementary method to conventional cancer therapies, such as chemotherapy, radiation therapy, or surgery.

An important benefit of NK cell treatment is its capacity to selectively attack a diverse array of cancer types. Contrary to traditional treatments that typically focus on a particular biochemical pathway or tumor marker, NK cells possess the capacity to identify and eradicate various types of cancer cells (19). Their ability to target a wide range of activities makes them highly successful against malignancies that have become resistant to conventional treatments or that have a high level of heterogeneity. Another significant benefit of NK cell treatment is its capacity to elicit an immunological memory response. Upon reintegration into the patient's body, NK cells possess the ability to not only eradicate existing cancer cells but also establish a durable immunological memory (20). This memory response enables the immune system to identify and react to cancer cells with greater efficiency in subsequent instances, perhaps offering a long-lasting defense against the reappearance of the illness.

NK cells possess the capacity to not only directly kill but also generate a range of cytokines and chemokines that can influence the tumor microenvironment. NK cells can secrete signaling molecules to attract other immune cells, such as dendritic cells and T cells, to the location of the tumor and amplify their anti-cancer functions (21). The interaction between various elements of the immune system might result in a mutually beneficial effect, enhancing the effectiveness of treatments.

Nevertheless, despite these encouraging benefits, there are still numerous obstacles that must be resolved in order to fully harness the promise of NK cell treatment. A significant impediment lies in the restricted accessibility of NK cells. Contrary to other immune cells, NK cells are found in significantly lower quantities in the bloodstream. The limited availability of NK cells has prompted the development of techniques to cultivate and sustain these cells in a laboratory setting while ensuring their functionality and effectiveness. An additional obstacle lies in the intricate interaction between NK cells and cancer cells. Cancer cells can utilize diverse strategies to elude or restrict the function of NK cells, including the reduction of activating receptors or the increase of inhibitory receptors. To achieve success in NK cell therapy, it is essential to overcome various measures used by the immune system to avoid detection. This needs a comprehensive understanding of the molecular pathways involved. Furthermore, achieving efficient transportation and targeted migration of NK cells to the tumor location can also pose a difficulty. It is essential to devise ways that improve the migration and infiltration of NK cells into solid tumors. This is because the tumor microenvironment can provide substantial obstacles to the effective targeting and elimination of cancer cells.

Notwithstanding these difficulties, NK cell treatment is exhibiting significant potential and has already exhibited promising outcomes in initial clinical trials. The therapy's capacity to enhance the body's innate immune response to cancer and its capability to selectively target a broad spectrum of cancers make it a captivating field of investigation. Through continued progress in manufacturing procedures, enhancement of NK cell activity, and enhanced understanding of the underlying biology, NK cell therapy holds the promise to transform cancer treatment and enhance patient outcomes in the future.

Metabolic Therapies

Targeting Cancer Metabolism

Metabolism encompasses the biochemical events taking place within cells to generate energy for diverse biological functions. Cancer cells possess a distinct metabolic process that enables them to sustain accelerated growth and reproduction. Their main source of energy is glucose metabolism, even when oxygen is available, which is referred to as the Warburg effect (22). The modified metabolism grants cancer cells a metabolic edge, enabling their survival and flourishing in the inhospitable tumor microenvironment.

The Warburg effect has undergone thorough investigation and is currently acknowledged as a fundamental metabolic characteristic of cancer cells. The objective of targeting cancer metabolism is to interfere with the altered metabolic processes by inhibiting certain metabolic pathways that are essential for the survival of cancer cells. A technique involves selectively inhibiting enzymes involved in glycolysis, the metabolic pathway by which cancer cells metabolize glucose to generate energy (23). A number of small compounds have been discovered that selectively hinder glycolytic enzymes, including hexokinase

and pyruvate kinase. These inhibitors have demonstrated encouraging anti-tumor effects in preclinical investigations and are presently being evaluated in clinical trials.

Aside from glycolysis, many metabolic pathways have been recognized as potential targets for cancer treatment. The pentose phosphate pathway (PPP) is a route that is involved in supplying cancer cells with the necessary components for cell growth and proliferation. Suppressing enzymes involved in the PPP has been demonstrated to hinder the development of cancer cells and increase their susceptibility to chemotherapy (24). Multiple inhibitors that target PPP enzymes are currently being developed and demonstrate potential in preclinical studies.

Fatty acid metabolism is a commonly disrupted metabolic route in cancer. Cancer cells exhibit an elevated requirement for fatty acids in order to sustain their accelerated growth. Suppressing the activity of particular enzymes that play a role in the production or absorption of fatty acids has been demonstrated to impede the proliferation of cancer cells and make them more responsive to chemotherapy (25). Currently, there are ongoing early clinical trials for a number of small compounds that specifically target fatty acid metabolism.

Directing therapeutic efforts on cancer metabolism has significant potential as a technique for treating cancer. By interfering with specific metabolic pathways that are essential for the survival of cancer cells, it is feasible to selectively eliminate cancer cells while preserving normal cells. This technique possesses the capacity to surmount the constraints of existing cancer therapies, such as resistance to drugs and toxicity. Aside from small-molecule inhibitors, alternative strategies for targeting cancer metabolism encompass the utilization of metabolic modulators, such as metformin, a commonly given medication for diabetes (26). Metformin has demonstrated antineoplastic effects in animal models and is presently undergoing clinical trials to assess its potential as an anticancer treatment (27). Additional metabolic regulators, such as dichloroacetate and phenformin, are also under investigation as potential treatments for cancer.

Although preclinical research has shown encouraging results, there are numerous obstacles in the pursuit of targeting cancer metabolism. A significant obstacle arises from the metabolic heterogeneity of malignancies, when distinct areas of a tumor display varying metabolic activity. The presence of such diversity poses challenges in properly targeting cancer metabolism, potentially leading to therapy failure and recurrence. Another obstacle arises from the possibility of normal tissue damage, since numerous metabolic pathways that are crucial for normal cellular function are also targeted in cancer cells. Hence, it is crucial to pinpoint distinct metabolic weaknesses of cancer cells that can be utilized without causing harm to healthy cells.

Metabolic Modulation for Cancer Treatment

The objective of metabolic modulation is to utilize the distinct metabolic traits of cancer cells in order to impede their proliferation and ultimately eliminate them. The Warburg effect refers to the phenomenon where cancer cells primarily depend on glucose as their primary source of energy. Metabolic modulation therapies try to deprive cancer cells of the necessary nutrients for their growth by specifically targeting their abnormal metabolism (28). An example of such a strategy is caloric restriction, which involves limiting the consumption of glucose and other nutrients, thus reducing the amount of fuel accessible to cancer cells.

Besides limiting calorie intake, the ketogenic diet has garnered interest as a possible approach to modulating metabolism. The body's metabolic process is altered by this diet, causing it to primarily utilize fat as its main energy source rather than glucose. The justification for this method is based on the fact that cancer cells have a restricted capacity to metabolize fat for energy, therefore denying them their preferred source of fuel.

Metabolic modulation therapies aim to specifically target metabolic enzymes that are vital for the rapid growth of cancer cells. Suppressing enzymes like hexokinase, which play a role in the glycolytic pathway, can interfere with the energy generation of cancer cells and impede their ability to survive (29). Furthermore, medications that specifically target enzymes engaged in the process of nucleotide synthesis, such as ribonucleotide reductase, have demonstrated encouraging outcomes in experiments conducted prior to clinical trials. Metabolic regulation extends beyond the direct targeting of cancer cell metabolism. Additionally, it encompasses medicines that influence the body's immune system to identify and combat cancer cells. Immunotherapy is an innovative method of cancer treatment that seeks to bolster the immune system's capacity to recognize and eradicate cancerous cells (30). Metabolic modulation therapies can optimize the effectiveness of immunotherapy by controlling the metabolic processes of immune cells and generating a conducive environment for their optimal functioning.

Metabolic modulation techniques provide the advantage of potentially lower toxicity as compared to conventional treatments like chemotherapy. By particularly focusing on the metabolic processes of cancer cells, these medicines have the potential to protect healthy cells from the harmful side effects that are typically associated with traditional treatments (31). Furthermore, metabolic modulation therapy can have the benefit of metabolic flexibility, enabling a customized approach tailored to an individual's unique metabolic profile.

Although preclinical studies have shown encouraging findings, there are still obstacles that must be overcome in order to develop and utilize metabolic modulation medicines. A significant challenge lies in the heterogeneity of cancer, where many types and subtypes of cancer cells may display distinct metabolic changes. It is essential for the efficacy of metabolic modulation therapies to be customized based on the specific cancer types and unique characteristics of patients. Another obstacle involves the identification of dependable biomarkers for assessing the efficacy of metabolic modulation therapy. The existing techniques for evaluating the effectiveness of these therapies are constrained and frequently indirect, posing challenges to appropriately appraising treatment outcomes. Creating resilient biomarkers that accurately represent alterations in cancer cell metabolism will empower clinicians to track patients' reactions to therapy and make treatment choices accordingly.

Combination Therapies

Immunotherapy with Other Modalities

Chemotherapy is frequently used in conjunction with immuno-

therapy. Chemotherapy refers to the administration of potent medications with the aim of eradicating cancerous cells throughout the entire body. While chemotherapy can effectively eradicate cancer cells, it simultaneously inflicts harm on healthy cells. By integrating immunotherapy with chemotherapy, one can augment the immune response against cancer cells while reducing the detrimental impact of chemotherapy on healthy cells (32).

Radiotherapy is another method that can be used in conjunction with immunotherapy. Radiotherapy employs ionizing radiation of high energy to eradicate cancerous cells inside a targeted region of the body. Evidence has demonstrated that radiation has the capacity to elicit an immune response targeting tumor cells. By integrating radiotherapy with immunotherapy, the immune response can be augmented, resulting in improved tumor management and potentially complete elimination (33).

Immunotherapy can be used with targeted therapies, as well as chemotherapy and radiotherapy. Targeted therapies are pharmaceutical agents that selectively focus on certain genetic alterations or proteins that are crucial for the proliferation and viability of malignant cells. Through the integration of targeted medicines and immunotherapy, it becomes feasible to assail cancer cells from many perspectives, hence augmenting the probability of achieving a favorable therapeutic outcome (34).

In addition, immunotherapy can be augmented by integrating other immunotherapeutic strategies to increase its effectiveness. An example of a method is adoptive cell transfer, which entails the extraction and amplification of a patient's own immune cells, specifically T cells, outside of the body, followed by their reintroduction into the patient. Through the integration of adoptive cell transfer and immunotherapy, it becomes feasible to enhance the immune response against cancer cells with greater efficacy (35).

An additional immunotherapeutic strategy that can be integrated with immunotherapy is the utilization of vaccinations. Vaccines have the ability to instruct the immune system to identify and combat cancerous cells. Through the integration of vaccinations and immunotherapy, it is feasible to augment the immune response and boost the likelihood of a triumphant cancer therapy (36).

Furthermore, continuing research is investigating the integration of immunotherapy with other developing treatment methods, including gene therapy and nanotechnology. Gene therapy entails the alteration of a patient's cells to augment their capacity to combat cancer cells. Nanotechnology employs microscopic particles to administer precise medicines directly to cancer cells. The integration of these nascent therapeutic methodologies with immunotherapy exhibits substantial potential for the advancement of cancer treatment in the future (37).

Therefore, immunotherapy has fundamentally transformed the domain of cancer treatment. Nevertheless, in order to enhance its effectiveness, scientists have investigated the integration of immunotherapy with other approaches, including chemotherapy, radiation, targeted therapies, adoptive cell transfer, vaccines, gene therapy, and nanotechnology. These combinations have the capacity to augment the immune response against cancer cells and boost patient outcomes. With the ongoing advancement of research, there is reason to be optimistic that these combinations may profoundly transform cancer treatment and bring us closer to a remedy.

Multi-Targeted Approaches

Multi-targeted techniques for cancer therapy involve treatment options that try to selectively target various pathways and substances that play a role in the genesis and progression of cancer (38). This approach acknowledges the intricacy of cancer biology and the reality that cancers frequently employ many pathways to endure and flourish. Multi-targeted medicines enhance the likelihood of efficiently eliminating cancer cells and inhibiting the development of drug resistance by simultaneously targeting numerous pathways.

The reason for employing multi-targeted methods is rooted in the diversity and flexibility of cancer cells. Tumors can become resistant to therapies that target a single specific molecule by either activating different signaling pathways or gaining mutations in the targeted molecule (39). Multi-targeted medicines, by concurrently addressing many pathways, diminish the probability of resistance and enhance the possibility of a long-lasting response. Moreover, cancer cells frequently rely on many interconnected pathways for their survival, thereby rendering multi-targeted strategies more potent in triggering cell death.

A key benefit of multi-targeted methods is their capacity to simultaneously target multiple vulnerabilities in cancer cells. These vulnerabilities encompass aberrant signaling pathways, angiogenesis, evasion of the immune system, and resistance to apoptosis. Multi-targeted medicines can exert a wide-ranging and mutually reinforcing effect on the development and survival of cancer cells by specifically addressing several aspects of tumor biology. Multiple approaches are utilized to accomplish the objective of treating multiple sites in cancer treatment. A method involves employing tiny compounds that attach to and hinder many targets. For instance, tyrosine kinase inhibitors like sunitinib and sorafenib effectively block the activity of certain receptor tyrosine kinases that play a role in angiogenesis, cell proliferation, and cell survival (40).

An alternative approach involves the amalgamation of various medications that target certain molecular pathways. This method capitalizes on the additive or synergistic benefits of combining medicines with distinct modes of action. An example of this is the synergistic effect shown in ovarian cancer when combining the DNA-damaging drug carboplatin with the targeted therapy olaparib, a poly(ADP-ribose) polymerase inhibitor. This combination enhances the effectiveness of both treatments (41).

Furthermore, immunotherapy has emerged as a multifaceted strategy for the treatment of cancer. Pembrolizumab and nivolumab are immune checkpoint inhibitors that hinder the interaction between immune checkpoints and their ligands, hence facilitating a stronger and longer-lasting immune response against tumors (42). This strategy simultaneously focuses on cancer cells themselves as well as the inhibitory signals that dampen the immune system, resulting in improved elimination of tumors.

Multi-targeted strategies have demonstrated encouraging outcomes in several forms of malignancies. Tyrosine kinase

inhibitors, including imatinib, have greatly transformed the management of chronic myeloid leukemia (43). Imatinib effectively elicits profound and long-lasting responses in most patients with chronic myeloid leukemia by specifically targeting the BCR-ABL fusion protein and other tyrosine kinases.

Another instance of an efficacious multi-targeted therapy is the amalgamation of trastuzumab and pertuzumab for breast cancer that is positive for the HER2 protein. Trastuzumab specifically targets the region outside of the cell of the HER2 protein, whereas pertuzumab inhibits the process of HER2 proteins joining together to form dimers (44). This combination has greatly enhanced outcomes for patients with HER2-positive breast cancer by effectively blocking both ligand-dependent and HER2-independent HER2 signaling.

In addition, PARP inhibitors, such as olaparib and rucaparib, have shown remarkable effectiveness in treating malignancies that have DNA repair abnormalities, such as ovarian and breast tumors with BRCA mutations (45). These drugs specifically focus on cancer cells that have impairments in DNA repair pathways while leaving normal cells unaffected. This strategy emphasizes the capacity to selectively target particular weaknesses in cancer cells.

Artificial Intelligence and Machine Learning in Cancer Treatment

AI and machine learning (ML) have made significant advancements in the field of cancer treatment, promising great potential for improving patient outcomes. AI algorithms are being increasingly used to analyze vast amounts of complex genomic and clinical data, helping identify patterns that can aid in accurate diagnosis and personalized treatment plans. ML models are capable of detecting early signs of cancer by screening medical images with exceptional accuracy, reducing errors, and enabling earlier interventions. Additionally, AI-enabled systems are being developed to predict patients' responses to certain treatments, allowing oncologists to tailor therapies accordingly. This integration of AI and ML into cancer treatment not only enhances diagnostic accuracy but also improves prognosis estimation, identifies biomarkers for targeted therapies, and optimizes radiation planning for effective tumor eradication while minimizing damage to healthy tissues. Overall, the utilization of AI and ML technologies holds immense promise in revolutionizing cancer care by ensuring precise diagnosis, tailoring treatments based on individual patients' profiles, and ultimately improving chances of survival.

Predictive Analytics for Treatment Response

The objective of cancer treatment is to optimize the likelihood of achieving remission or long-term survival while reducing the occurrence of undesirable consequences. Nevertheless, the response to treatment can exhibit significant variability among patients, posing a challenge for oncologists in determining the optimal method. AI predictive analytics has the capacity to transform cancer therapy by utilizing machine learning methods to examine clinical, genetic, and imaging data in order to forecast treatment results (46).

The efficacy of AI predictive analytics for cancer treatment hinges on the availability of extensive data sets. AI algorithms can acquire knowledge from electronic health records, genomic databases, and medical imaging libraries, as these sources all contribute to the information pool (47). Through the analysis of extensive data sets, artificial intelligence algorithms can detect intricate patterns and correlations that may not be immediately evident to human analysts. This enables more precise forecasts of the response to therapy.

Oncologists encounter a multitude of obstacles when determining the optimal treatment for individual patients. AI predictive analytics can aid in this decision-making process by offering recommendations based on empirical evidence (48). AI algorithms can enhance treatment outcomes by providing individualized recommendations based on specific patient attributes, like age, gender, and genetic variations.

AI predictive analytics can also enhance cancer treatment by optimizing clinical trials and advancing medication development (49). Through the analysis of historical data on treatment responses, AI algorithms have the ability to determine the specific parameters that play a role in determining the success or failure of a treatment. Subsequently, this data can be utilized to enhance the design of trials, pinpoint patient subgroups that could potentially gain advantages from particular treatments, and steer the advancement of novel therapeutics.

Nevertheless, the utilization of AI predictive analytics in cancer treatment also poses difficulties and constraints (50). The accuracy of AI models can be greatly influenced by the quality and comprehensiveness of the data utilized for training. Acquiring and managing extensive datasets can be a laborious and resource-demanding endeavor. Furthermore, the comprehensibility of AI algorithms continues to be a difficulty. Although these models are capable of producing precise predictions, comprehending the fundamental rationales behind their judgments can be challenging, hence restricting their implementation in clinical practice.

The application of AI predictive analytics in cancer treatment also gives rise to ethical problems. Ensuring the confidentiality and protection of sensitive medical information is crucial for maintaining patient privacy and data security. Stringent measures must be implemented to prevent unwanted entry and guarantee that data is utilized for its designated objective. Moreover, ensuring openness in AI algorithms is crucial for establishing trust among patients and healthcare practitioners, hence promoting the adoption and acceptance of these technologies.

Drug discovery and development

An essential component of the process of discovering and developing drugs is gaining a comprehensive understanding of the genetics of cancer. AI algorithms have the capability to examine extensive genomic datasets in order to detect genetic alterations and forecast the effectiveness of particular medications for individual patients (51). Through the integration of genomic and clinical data, scientists have the ability to create individualized treatment strategies and enhance patient outcomes.

AI-driven virtual screening methods facilitate swift identification of prospective medication candidates. AI algorithms can evaluate the probability of a compound's efficacy against cancer targets by analyzing its molecular structures and attrib-

utes in relation to recognized compounds (52). This greatly expedites the early screening phases, reducing the number of possible medication candidates that can be further examined. AI has the capability to create prediction models using extensive data, enabling researchers to forecast the pharmacokinetics, toxicity, and effectiveness of medications (53). These models can aid in the prioritization of drug candidates for subsequent research, thereby diminishing the expenses and time needed for preclinical and clinical studies and ultimately enhancing the efficacy of drug development.

AI systems can examine extensive databases of authorized medications and discover possible candidates for cancer treatment by revealing hidden therapeutic effects (54). Utilizing current medications for novel applications can significantly diminish the duration and expenses linked to the development of new drugs, resulting in the expedited availability of possible therapies for patients (55). AI systems have the capability to examine patient data and detect trends that might forecast negative occurrences, possible drug toxicities, and interactions. AI aids in the creation of safer medications and treatment plans by issuing early alerts, thereby guaranteeing patient safety during the entire drug development procedure. AI has the ability to enhance clinical trials by identifying appropriate patient groups and finding the optimal dosage and treatment timetable (56). Researchers can effectively enlist patients, enhance the success rates of trials, and expedite the approval procedure for novel cancer therapies.

Although AI has great potential, there are some obstacles that must be overcome. The concerns encompassed are related to privacy, the assurance of data accuracy, the validation of AI predictions using real-world evidence, and the supervision of regulatory compliance (57). To ensure trust and fairness, it is crucial to prioritize ethical factors such as transparency, bias, and responsibility in AI systems.

The use of AI in the process of discovering and developing drugs for cancer is a highly promising area that has not yet been fully explored. The progress in machine learning, natural language processing, and picture identification will augment the powers of AI in discovering novel treatment choices, forecasting patient reactions, and maximizing therapeutic intervention. The responsible implementation and acceptance of AI in cancer treatment development will be propelled by the collaborative endeavors of researchers, pharmaceutical businesses, and regulatory agencies.

Conclusions

The incorporation of adoptive cell transfer, metabolic therapy, and AI into cancer treatment has resulted in substantial advancements in the field. Cancerous cells in the body can be targeted and eliminated by the process of adoptive cell transfer, which entails designing immune cells to do so. In order to combat malignancies, this individualized strategy makes use of the patient's own immune system to its full potential. The goal of metabolic therapy, on the other hand, is to selectively deprive cancer cells of the nutrients and energy sources that are necessary for their existence by modifying the metabolic pathways that are present within cancer cells. This innovative method takes use of weaknesses that are unique to tumor cells while avoiding damage to healthy tissues on the other hand. Additionally, artificial intelligence technologies have changed the treatment of cancer by providing precise diagnostic capabilities, predicting treatment outcomes, optimizing drug delivery systems, and generating personalized therapeutic regimens based on the genetic profiles of patients. These advances, when taken together, present a viable avenue for more effective cancer treatments with minimal side effects. They also underscore the enormous potential for synergistic methods in the fight against this debilitating illness.

ACT, an immunotherapy technique, entails altering a patient's immune cells to identify and attack cancer cells (58). This novel approach has demonstrated exceptional efficacy in the treatment of hematologic malignancies, such as leukemia and lymphoma. Genetically engineered T cells, known as CAR-T cells, have been successfully transferred to patients who have tried all available treatments, resulting in remarkable rates of remission.

Metabolic therapy, a cutting-edge method gaining popularity in cancer treatment, aims to specifically target the modified metabolism of cancer cells. These cells predominantly depend on glucose fermentation, also referred to as the Warburg effect, to meet their energy requirements. Scientists are investigating methods to take advantage of this weakness in metabolism by creating medications that interfere with the metabolic processes of cancer cells while leaving healthy cells unharmed (59).

The integration of ACT with metabolic therapy has significant potential to improve the outcomes of cancer treatment. By enhancing the immune system through ACT and concurrently depleting cancer cells of their energy source by metabolic therapy, the combined effect may surpass tumor resistance and diminish the occurrence of relapse.

AI, due to its capacity to evaluate extensive quantities of genomic and clinical data, has become a formidable weapon in the field of cancer research. AI algorithms have the capability to forecast the outcomes of treatments, discover new targets for therapy, and enhance individualized treatment choices by combining data from many sources, including genetics, imaging, and pathology (60). An exceptional application of AI in cancer research is its effectiveness in identifying and categorizing different forms of cancer (61). AI systems have the capability to examine gene expression patterns and detect distinct molecular fingerprints linked to various subcategories of cancer. Having this knowledge allows clinicians to customize therapies based on the unique characteristics of a patient's tumor, hence maximizing the effectiveness of therapy.

AI can aid in predicting therapy responses and evaluating prognosis by utilizing a patient's genomic profile, in addition to identifying subtypes. Through the analysis of extensive historical patient data, artificial intelligence systems have the capability to produce precise forecasts, enabling doctors to make well-informed judgments regarding treatment alternatives. AI is essential in accelerating drug discovery by aiding in the identification of prospective therapeutic targets. By analyzing extensive biological literature, AI algorithms can discover previously undisclosed correlations among genes, proteins, and pathways, offering crucial insights for the advancement of novel medi-

cines.

Integrating AI with ACT and metabolic therapy can significantly improve the effectiveness of cancer treatment. AI algorithms can aid in determining the optimal candidate for ACT by assessing the patient's immunological profile, tumor characteristics, and metabolic parameters. This method guarantees a customized treatment strategy specifically designed for each unique patient.

Except for the vast promise of these groundbreaking methods, numerous obstacles remain. The use of ACT and metabolic therapy still raises safety issues, and the improvement of AI algorithms for clinical decision-making is a continuous endeavor. Moreover, the exorbitant expenses associated with the implementation of these technologies create obstacles to achieving mass accessibility.■

References

1. Mukherjee AG, Wanjari UR, Namachivayam A, Murali R, Prabakaran DS, Ganesan R, Renu K, Dey A, Vellingiri B, Ramanathan G, Doss C GP, Gopalakrishnan AV. Role of immune cells and receptors in cancer treatment: An immunotherapeutic approach. Vaccines (Basel) 2022; 10(9):1493. DOI: https://doi.org/10.3390/vaccines10091493
2. Nassar SF, Raddassi K, Ubhi B, Doktorski J, Abulaban A. Precision medicine: Steps along the road to combat human cancer. Cells 2020; 9(9):2056. DOI: https://doi.org/10.3390/cells9092056
3. Gonçalves GAR, Paiva RMA. Gene therapy: advances, challenges and perspectives. Einstein (Sao Paulo) 2017; 15(3):369-375. DOI: https://doi.org/10.1590/S1679-45082017RB4024
4. Strianese O, Rizzo F, Ciccarelli M, Galasso G, D'Agostino Y, Salvati A, Del Giudice C, Tesorio P, Rusciano MR. Precision and personalized medicine: How genomic approach improves the management of cardiovascular and neurodegenerative disease. Genes (Basel) 2020; 11(7):747. DOI: https://doi.org/10.3390/genes11070747
5. Baranwal J, Barse B, Di Petrillo A, Gatto G, Pilia L, Kumar A. Nanoparticles in cancer diagnosis and treatment. Materials (Basel) 2023; 16(15):5354. DOI: https://doi.org/10.3390/ma16155354
6. Chehelgerdi M, Chehelgerdi M, Allela OQB, Pecho RDC, Jayasankar N, Rao DP, Thamaraikani T, Vasanthan M, Viktor P, Lakshmaiya N, Saadh MJ, Amajd A, Abo-Zaid MA, Castillo-Acobo RY, Ismail AH, Amin AH, Akhavan-Sigari R. Progressing nanotechnology to improve targeted cancer treatment: Overcoming hurdles in its clinical implementation. Mol Cancer 2023; 22(1):169. DOI: https://doi.org/10.1186/s12943-023-01865-0
7. Shiravand Y, Khodadadi F, Kashani SMA, Hosseini-Fard SR, Hosseini S, Sadeghirad H, Ladwa R, O'Byrne K, Kulasinghe A. Immune checkpoint inhibitors in cancer therapy. Curr Oncol 2022; 29(5):3044-3060. DOI: https://doi.org/10.3390/curroncol29050247
8. Riella LV, Paterson AM, Sharpe AH, Chandraker A. Role of the PD-1 pathway in the immune response. Am J Transplant 2012; 12(10):2575-2587. DOI: https://doi.org/10.1111/j.1600-6143.2012.04224.x
9. Alsaab HO, Sau S, Alzhrani R, Tatiparti K, Bhise K, Kashaw SK, Iyer AK. PD-1 and PD-L1 checkpoint signaling inhibition for cancer immunotherapy: Mechanism, combinations, and clinical outcome. Front Pharmacol 2017; 8:561. DOI: https://doi.org/10.3389/fphar.2017.00561
10. Buchbinder EI, Desai A. CTLA-4 and PD-1 pathways: Similarities, differences, and implications of their inhibition. Am J Clin Oncol 2016; 39(1):98-106. DOI: https://doi.org/10.1097/COC.0000000000000239
11. Okobi TJ, Uhomoibhi TO, Akahara DE, Odoma VA, Sanusi IA, Okobi OE, Umana I, Okobi E, Okonkwo CC, Harry NM. Immune checkpoint inhibitors as a treatment option for bladder cancer: Current evidence. Cureus 2023; 15(6):e40031. DOI: https://doi.org/10.7759/cureus.40031
12. Brahmer JR, Lacchetti C, Schneider BJ, Atkins MB, Brassil KJ, Caterino JM, Chau I, Ernstoff MS, Gardner JM, Ginex P, Hallmeyer S, Holter Chakrabarty J, Leighl NB, Mammen JS, McDermott DF, Naing A, Nastoupil LJ, Phillips T, Porter LD, Puzanov I, Reichner CA, Santomasso BD, Seigel C, Spira A, Suarez-Almazor ME, Wang Y, Weber JS, Wolchok JD, Thompson JA; National comprehensive cancer network. management of immune-related adverse events in patients treated with immune checkpoint inhibitor therapy: American Society of Clinical Oncology clinical practice guideline. J Clin Oncol 2018; 36(17):1714-1768. DOI: https://doi.org/10.1200/JCO.2017.77.6385
13. Basudan AM. The role of immune checkpoint inhibitors in cancer therapy. Clin Pract 2022; 13(1):22-40. DOI: https://doi.org/10.3390/clinpract13010003
14. Hernández-López A, Téllez-González MA, Mondragón-Terán P, Meneses-Acosta A. Chimeric antigen receptor-t cells: A pharmaceutical scope. Front Pharmacol 2021; 12:720692. DOI: https://doi.org/10.3389/fphar.2021.720692
15. Dotti G, Gottschalk S, Savoldo B, Brenner MK. Design and development of therapies using chimeric antigen receptor-expressing T cells. Immunol Rev 2014; 257(1):107-126. DOI: https://doi.org/10.1111/imr.12131
16. Cappell KM, Kochenderfer JN. Long-term outcomes following CAR T cell therapy: What we know so far.

Nat Rev Clin Oncol 2023; 20(6):359-371. DOI: https://doi.org/10.1038/s41571-023-00754-1

17. Messmer AS, Que YA, Schankin C, Banz Y, Bacher U, Novak U, Pabst T. CAR T-cell therapy and critical care: A survival guide for medical emergency teams. Wien Klin Wochenschr 2021; 133(23-24):1318-1325. DOI: https://doi.org/10.1007/s00508-021-01948-2
18. Levine BL, Miskin J, Wonnacott K, Keir C. Global manufacturing of CAR T Cell therapy. Mol Ther Methods Clin Dev 2016; 4:92-101. DOI: https://doi.org/10.1016/j.omtm.2016.12.006
19. Fesnak AD. The challenge of variability in chimeric antigen receptor T cell manufacturing. Regen Eng Transl Med 2020; 6(3):322-329. DOI: https://doi.org/10.1007/s40883-019-00124-3
20. Liu Z, Zhou Z, Dang Q, Xu H, Lv J, Li H, Han X. Immunosuppression in tumor immune microenvironment and its optimization from CAR-T cell therapy. Theranostics 2022; 12(14):6273-6290. DOI: https://doi.org/10.7150/thno.76854
21. Zhang C, Liu J, Zhong JF, Zhang X. Engineering CAR-T cells. Biomark Res 2017; 5:22. DOI: https://doi.org/10.1186/s40364-017-0102-y
22. Kumar AR, Devan AR, Nair B, Vinod BS, Nath LR. Harnessing the immune system against cancer: Current immunotherapy approaches and therapeutic targets. Mol Biol Rep 2021; 48(12):8075-8095. DOI: https://doi.org/10.1007/s11033-021-06752-9
23. Liu D, Che X, Wang X, Ma C, Wu G. tumor vaccines: Unleashing the power of the immune system to fight cancer. Pharmaceuticals (Basel) 2023; 16(10):1384. DOI: https://doi.org/10.3390/ph16101384
24. Enokida T, Moreira A, Bhardwaj N. Vaccines for immunoprevention of cancer. J Clin Invest 2021; 131(9):e146956. DOI: https://doi.org/10.1172/JCI146956
25. Le I, Dhandayuthapani S, Chacon J, Eiring AM, Gadad SS. Harnessing the immune system with cancer vaccines: From prevention to therapeutics. Vaccines (Basel) 2022; 10(5):816. DOI: https://doi.org/10.3390/vaccines10050816
26. Cheever MA, Higano CS. PROVENGE (Sipuleucel-T) in prostate cancer: The first FDA-approved therapeutic cancer vaccine. Clin Cancer Res 2011; 17(11):3520-3526. DOI: https://doi.org/10.1158/1078-0432.CCR-10-3126
27. Kantoff PW, Higano CS, Shore ND, Berger ER, Small EJ, Penson DF, Redfern CH, Ferrari AC, Dreicer R, Sims RB, Xu Y, Frohlich MW, Schellhammer PF; IMPACT Study Investigators. Sipuleucel-T immunotherapy for castration-resistant prostate cancer. N Engl J Med 2010; 363(5):411-422. DOI: https://doi.org/10.1056/NEJMoa1001294
28. Fan T, Zhang M, Yang J, Zhu Z, Cao W, Dong C. Therapeutic cancer vaccines: Advancements, challenges, and prospects. Signal Transduct Target Ther 2023; 8(1):450. DOI: https://doi.org/10.1038/s41392-023-01674-3
29. Liu J, Fu M, Wang M, Wan D, Wei Y, Wei X. Cancer vaccines as promising immuno-therapeutics: Platforms and current progress. J Hematol Oncol 2022; 15(1):28. DOI: https://doi.org/10.1186/s13045-022-01247-x
30. Berger MF, Mardis ER. The emerging clinical relevance of genomics in cancer medicine. Nat Rev Clin Oncol 2018; 15(6):353-365. DOI: https://doi.org/10.1038/s41571-018-0002-6
31. Wang M, Yu L, Wei X, Wei Y. Role of tumor gene mutations in treatment response to immune checkpoint blockades. Precis Clin Med 2019; 2(2):100-109. DOI: https://doi.org/10.1093/pcmedi/pbz006
32. Jardim DL, Goodman A, de Melo Gagliato D, Kurzrock R. The challenges of tumor mutational burden as an immunotherapy biomarker. Cancer Cell 2021; 39(2):154-173. DOI: https://doi.org/10.1016/j.ccell.2020.10.001
33. Nagahashi M, Shimada Y, Ichikawa H, Kameyama H, Takabe K, Okuda S, Wakai T. Next generation sequencing-based gene panel tests for the management of solid tumors. Cancer Sci 2019; 110(1):6-15. DOI: https://doi.org/10.1111/cas.13837
34. Bai R, Chen N, Li L, Du N, Bai L, Lv Z, Tian H, Cui J. Mechanisms of cancer resistance to immunotherapy. Front Oncol 2020; 10:1290. DOI: https://doi.org/10.3389/fonc.2020.01290
35. Hicks JK, Dunnenberger HM, Gumpper KF, Haidar CE, Hoffman JM. Integrating pharmacogenomics into electronic health records with clinical decision support. Am J Health Syst Pharm 2016; 73(23):1967-1976. DOI: https://doi.org/10.2146/ajhp160030
36. Pottier C, Fresnais M, Gilon M, Jérusalem G, Longuespée R, Sounni NE. Tyrosine kinase inhibitors in cancer: Breakthrough and challenges of targeted therapy. Cancers (Basel) 2020; 12(3):731. DOI: https://doi.org/10.3390/cancers12030731
37. Kim M, Baek M, Kim DJ. Protein tyrosine signaling and its potential therapeutic implications in carcinogenesis. Curr Pharm Des 2017; 23(29):4226-4246. DOI: https://doi.org/10.2174/1381612823666170616082125
38. Kang ZJ, Liu YF, Xu LZ, Long ZJ, Huang D, Yang Y, Liu B, Feng JX, Pan YJ, Yan JS, Liu Q. The Philadelphia chromosome in leukemogenesis. Chin J Cancer 2016; 35:48. DOI: https://doi.org/10.1186/s40880-016-0108-0
39. Kirschner J, Cathomen T. Gene therapy for monogenic inherited disorders. Dtsch Arztebl Int 2020; 117(51-52):878-885. DOI: https://doi.org/10.3238/arztebl.2020.0878
40. Kole R, Krainer AR, Altman S. RNA therapeutics: Beyond RNA interference and antisense oligonucleotides. Nat Rev Drug Discov 2012; 11(2):125-140. DOI: https://doi.org/10.1038/nrd3625
41. Theodoridis PR, Bokros M, Marijan D, Balukoff NC, Wang D, Kirk CC, Budine TD, Goldsmith HD, Wang M, Audas TE, Lee S. Local translation in nuclear condensate amyloid bodies. Proc Natl Acad Sci U S A 2021; 118(7):e2014457118. DOI: https://doi.org/10.1073/pnas.2014457118
42. Waarts MR, Stonestrom AJ, Park YC, Levine RL.

Targeting mutations in cancer. J Clin Invest 2022; 132(8):e154943. DOI: https://doi.org/10.1172/JCI154943

43. Mahdieh N, Rabbani B. An overview of mutation detection methods in genetic disorders. Iran J Pediatr 2013; 23(4):375-388.
44. Yip HYK, Papa A. Signaling pathways in cancer: Therapeutic targets, combinatorial treatments, and new developments. Cells 2021; 10(3):659. DOI: https://doi.org/10.3390/cells10030659
45. Tewabe A, Abate A, Tamrie M, Seyfu A, Abdela Siraj E. Targeted drug delivery - from magic bullet to nanomedicine: Principles, challenges, and future perspectives. J Multidiscip Healthc 2021; 14:1711-1724. DOI: https://doi.org/10.2147/JMDH.S313968
46. Wang EC, Wang AZ. Nanoparticles and their applications in cell and molecular biology. Integr Biol (Camb) 2014; 6(1):9-26. DOI: https://doi.org/10.1039/c3ib40165k
47. Nakamura Y, Mochida A, Choyke PL, Kobayashi H. Nanodrug delivery: Is the enhanced permeability and retention effect sufficient for curing cancer? Bioconjug Chem 2016; 27(10):2225-2238. DOI: https://doi.org/10.1021/acs.bioconjchem.6b00437
48. Yao Y, Zhou Y, Liu L, Xu Y, Chen Q, Wang Y, Wu S, Deng Y, Zhang J, Shao A. Nanoparticle-based drug delivery in cancer therapy and its role in overcoming drug resistance. Front Mol Biosci 2020; 7:193. DOI: https://doi.org/10.3389/fmolb.2020.00193
49. Ezike TC, Okpala US, Onoja UL, Nwike CP, Ezeako EC, Okpara OJ, Okoroafor CC, Eze SC, Kalu OL, Odoh EC, Nwadike UG, Ogbodo JO, Umeh BU, Ossai EC, Nwanguma BC. Advances in drug delivery systems, challenges and future directions. Heliyon 2023; 9(6):e17488. DOI: https://doi.org/10.1016/j.heliyon.2023.e17488
50. Jeelani S, Reddy RC, Maheswaran T, Asokan GS, Dany A, Anand B. Theranostics: A treasured tailor for tomorrow. J Pharm Bioallied Sci 2014; 6(Suppl 1):S6-S8. DOI: https://doi.org/10.4103/0975-7406.137249
51. Janib SM, Moses AS, MacKay JA. Imaging and drug delivery using theranostic nanoparticles. Adv Drug Deliv Rev 2010; 62(11):1052-1063. DOI: https://doi.org/10.1016/j.addr.2010.08.004
52. Cescon DW, Kalinsky K, Parsons HA, Smith KL, Spears PA, Thomas A, Zhao F, DeMichele A. Therapeutic targeting of minimal residual disease to prevent late recurrence in hormone-receptor positive breast cancer: Challenges and new approaches. Front Oncol 2022; 11:667397. DOI: https://doi.org/10.3389/fonc.2021.667397
53. Abyzova E, Dogadina E, Rodriguez RD, Petrov I, Kolesnikova Y, Zhou M, Liu C, Sheremet E. Beyond Tissue replacement: The Emerging role of smart implants in healthcare. Mater Today Bio 2023; 22:100784. DOI: https://doi.org/10.1016/j.mtbio.2023.100784
54. Alghamdi MA, Fallica AN, Virzì N, Kesharwani P, Pittalà V, Greish K. The promise of nanotechnology in personalized medicine. J Pers Med 2022; 12(5):673. DOI: https://doi.org/10.3390/jpm12050673
55. Stefanoudakis D, Kathuria-Prakash N, Sun AW, Abel M, Drolen CE, Ashbaugh C, Zhang S, Hui G, Tabatabaei YA, Zektser Y, Lopez LP, Pantuck A, Drakaki A. The potential revolution of cancer treatment with CRISPR technology. Cancers (Basel) 2023; 15(6):1813. DOI: https://doi.org/10.3390/cancers15061813
56. Lee HM. Strategies for manipulating T cells in cancer immunotherapy. Biomol Ther (Seoul) 2022; 30(4):299-308. DOI: https://doi.org/10.4062/biomolther.2021.180
57. Vaghari-Tabari M, Hassanpour P, Sadeghsoltani F, Malakoti F, Alemi F, Qujeq D, Asemi Z, Yousefi B. CRISPR/Cas9 gene editing: A new approach for overcoming drug resistance in cancer. Cell Mol Biol Lett 2022; 27(1):49. DOI: https://doi.org/10.1186/s11658-022-00348-2
58. Yuan M, Webb E, Lemoine NR, Wang Y. CRISPR-Cas9 as a powerful tool for efficient creation of oncolytic viruses. Viruses 2016; 8(3):72. DOI: https://doi.org/10.3390/v8030072
59. Akram F, Haq IU, Sahreen S, Nasir N, Naseem W, Imitaz M, Aqeel A. CRISPR/Cas9: A revolutionary genome editing tool for human cancers treatment. Technol Cancer Res Treat 2022; 21:15330338221132078. DOI: https://doi.org/10.1177/15330338221132078
60. Azangou-Khyavy M, Ghasemi M, Khanali J, Boroomand-Saboor M, Jamalkhah M, Soleimani M, Kiani J. CRISPR/Cas: From tumor gene editing to T cell-based immunotherapy of cancer. Front Immunol 2020; 11:2062. DOI: https://doi.org/10.3389/fimmu.2020.02062
61. Jhawar SR, Thandoni A, Bommareddy PK, Hassan S, Kohlhapp FJ, Goyal S, Schenkel JM, Silk AW, Zloza A. Oncolytic viruses-natural and genetically engineered cancer immunotherapies. Front Oncol 2017; 7:202. DOI: https://doi.org/10.3389/fonc.2017.00202
62. Das SK, Menezes ME, Bhatia S, Wang XY, Emdad L, Sarkar D, Fisher PB. Gene therapies for cancer: Strategies, challenges and successes. J Cell Physiol 2015; 230(2):259-71. DOI: https://doi.org/10.1002/jcp.24791
63. Kaufman HL, Kohlhapp FJ, Zloza A. Oncolytic viruses: A new class of immunotherapy drugs. Nat Rev Drug Discov 2015;14(9):642-662. DOI: https://doi.org/10.1038/nrd4663. Erratum in: Nat Rev Drug Discov 2016; 15(9):660.
64. Scanlan H, Coffman Z, Bettencourt J, Shipley T, Bramblett DE. Herpes simplex virus 1 as an oncolytic viral therapy for refractory cancers. Front Oncol 2022; 12:940019. DOI: https://doi.org/10.3389/fonc.2022.940019
65. Jogalekar MP, Rajendran RL, Khan F, Dmello C, Gangadaran P, Ahn BC. CAR T-Cell-Based gene therapy for cancers: New perspectives, challenges, and clinical developments. Front Immunol 2022; 13:925985. DOI: https://doi.org/10.3389/fimmu.2022.925985

Received: October 06, 2023 | Revised: November 15, 2023 | Accepted: November 22, 2023