Check for updates

(REVIEW ARTICLE)

Reviewing the progress of cancer research in the USA

Israel Osejie Okoduwa [1, *], Bankole Ibrahim Ashiwaju [2], Jane Osareme Ogugua [2], Jeremiah Olawumi Arowoogun [3], Kehinde Feranmi Awonuga [4] and Evangel Chinyere Anyanwu [5]

[1] Independent Researcher, England, United Kingdom.
[2] Independent Researcher, Lagos, Nigeria.
[3] Bharat Serums and Vaccines Limited, Lagos, Nigeria.
[4] Independent Researcher, United Kingdom.
[5] Independent Researcher, Nebraska, USA.

Abstract

This review provides a comprehensive analysis of the progress made in cancer research within the United States. Over the past few decades, significant strides have been taken to understand the complexities of cancer, leading to breakthroughs in diagnostics, treatment modalities, and overall patient care. The review explores key themes, including advancements in genomic medicine, immunotherapy, and personalized treatment approaches. Advancements in genomic medicine have emerged as a cornerstone of cancer research, allowing for a deeper understanding of the genetic basis of various cancers. The integration of precision medicine techniques has facilitated the identification of specific genetic mutations, paving the way for targeted therapies tailored to individual patients. Genomic profiling has not only enhanced diagnostic accuracy but has also provided valuable insights into cancer heterogeneity, guiding researchers toward more effective and personalized treatment strategies. Immunotherapy has revolutionized cancer treatment by harnessing the body's immune system to target and eliminate cancer cells. The review delves into the remarkable progress in developing immune checkpoint inhibitors, adoptive cell therapies, and cancer vaccines. These innovations have shown unprecedented success in treating previously challenging malignancies, offering new hope for patients with advanced-stage cancers. The concept of personalized medicine is further explored, emphasizing the shift from a one-size-fits-all approach to tailoring treatments based on individual patient characteristics. The advent of liquid biopsies and advanced imaging techniques has enabled real-time monitoring of treatment responses, facilitating timely adjustments and improving overall patient outcomes. Despite these advancements, the review acknowledges persistent challenges, such as the need for enhanced collaboration between research institutions, the imperative for increased funding, and the importance of addressing healthcare disparities in cancer outcomes. The ongoing commitment to interdisciplinary research, translational initiatives, and a patient-centered approach is emphasized as essential for overcoming these challenges and further propelling the field of cancer research in the USA. In conclusion, this review paints a comprehensive picture of the remarkable progress in cancer research within the United States. The integration of genomic insights, immunotherapeutic breakthroughs, and personalized treatment approaches underscores a promising future for cancer patients, while acknowledging the necessity of continued efforts to address existing challenges and propel the field toward even greater advancements.

Keywords: Cancer; Diagnosis; Medicine; Research; Progress

1. Introduction

Cancer, a pervasive and formidable adversary, continues to exert a profound impact on global public health (Gao and Homayoonfal, 2023). With its prevalence transcending geographical boundaries, it has become a critical focal point for

---

* Corresponding author: Israel Osejie Okoduwa

scientific inquiry and medical innovation. The United States, at the forefront of cancer research, has witnessed substantial strides in understanding, diagnosing, and treating various forms of cancer (Beltrami *et al.*, 2022). This review delves into the progress made in cancer research within the USA, examining the multifaceted dimensions of this ongoing battle against a complex and resilient foe.

The pervasive nature of cancer is underscored by its alarming prevalence and profound impact on individuals, families, and communities (Adamczak *et al.*, 2023). Statistics reveal an increasing burden, with cancer being a leading cause of morbidity and mortality. The diversity of cancer types, each presenting unique challenges, emphasizes the urgency of comprehensive research endeavors to mitigate its impact on public health (Dewani *et al.*, 2023).

Cancer research holds pivotal significance in the quest for improved diagnostics, innovative treatment modalities, and enhanced patient outcomes (Elmore *et al.*, 2021). Advancements in understanding the molecular underpinnings of cancer have led to groundbreaking developments in targeted therapies, immunotherapy, and personalized medicine (Rai *et al.*, 2023). Such progress not only enhances the precision of diagnostics but also contributes to more effective and tailored treatment strategies, ultimately improving the quality of life for individuals affected by cancer.

The purpose of this review is to critically examine the trajectory of cancer research within the United States. By assessing the progress made in recent years, we aim to provide insights into the current state of the field, highlighting key achievements, emerging trends, and persistent challenges. This evaluation is crucial for understanding the impact of research initiatives on the evolving landscape of cancer care, guiding future directions, and ultimately contributing to the advancement of knowledge and therapeutic interventions in the fight against cancer.

As we embark on this study of progress, challenges, and future prospects, it is with the recognition that the pursuit of knowledge and innovation in cancer research is integral to reshaping the narrative of this pervasive disease and fostering hope for those affected.

2. Genomic Medicine Advancements: Unraveling the Genetic Tapestry of Cancer

In the realm of cancer research, the advent of genomic medicine has heralded a transformative era, offering unprecedented insights into the genetic underpinnings of various cancers (Raghani *et al.*, 2024). This multidisciplinary field integrates genomics, bioinformatics, and clinical medicine to unravel the complexities of the human genome and has played a pivotal role in advancing our understanding of cancer biology. This comprehensive review explores the overarching role of genomic medicine, detailing the progress made in decoding the genetic basis of cancers and the transformative impact of genomic profiling on diagnostics and personalized treatment strategies.

Genomic medicine represents a paradigm shift in healthcare, moving from a focus on symptoms and organ systems to a molecular understanding of diseases (Conte *et al.*, 2020). At its core, genomic medicine involves the analysis of an individual's complete set of genes, known as the genome, to identify genetic variations that may contribute to health or disease. In the context of cancer research, this approach aims to uncover the specific genetic alterations that drive the initiation, progression, and response to treatment in various cancer types.

The human genome, comprising over 20,000 protein-coding genes and a myriad of non-coding elements, is a dynamic blueprint that governs the intricate dance of cellular processes. Genomic medicine employs advanced technologies, such as next-generation sequencing, to unravel this genetic tapestry, allowing researchers and clinicians to identify mutations, copy number variations, and other genomic alterations associated with cancer development (de Álava, 2024).

The progression of cancer is intrinsically linked to alterations in the genome. Over the years, genomic medicine has made remarkable strides in elucidating the genetic landscapes of diverse cancers. Large-scale genomic initiatives, such as The Cancer Genome Atlas (TCGA), have systematically cataloged genomic alterations across numerous cancer types, providing a wealth of data for researchers to analyze (Reyna *et al.*, 2020).

Genomic studies have unveiled a plethora of driver mutations—genetic alterations that confer a selective growth advantage to cancer cells. These mutations, often found in oncogenes or tumor suppressor genes, drive uncontrolled cell proliferation, evasion of apoptosis, and other hallmarks of cancer. For instance, mutations in the BRAF gene are prevalent in melanoma, while mutations in the TP53 gene are implicated in various cancers, including breast and lung cancers.

Genomic research has shed light on the inherent heterogeneity within cancers, recognizing that tumors from different individuals or even within the same patient can harbor distinct genetic profiles. This understanding of intra-tumor and inter-tumor heterogeneity has profound implications for treatment strategies, emphasizing the need for personalized approaches tailored to the unique genetic makeup of each patient's cancer (Dujardin *et al.*, 2021).

The integration of genomic profiling into cancer diagnostics has revolutionized the way clinicians approach the identification and treatment of malignancies. Genomic information provides a molecular roadmap that goes beyond traditional histological classifications, allowing for a more precise understanding of the underlying biology of each tumor.

Genomic profiling enables the identification of specific molecular alterations driving cancer growth. Molecular diagnostics, including tests for mutations, rearrangements, and gene expression patterns, contribute to a more accurate and comprehensive diagnosis (Johnson *et al.*, 2020). For example, testing for HER2 amplification in breast cancer or EGFR mutations in lung cancer helps guide treatment decisions by identifying patients who may benefit from targeted therapies.

The era of targeted therapies has been ushered in by the insights gained from genomic research. Targeted therapies are designed to specifically inhibit the activity of proteins or pathways that are aberrantly activated in cancer cells due to specific genetic alterations (Peng *et al.*, 2022). Examples include tyrosine kinase inhibitors targeting EGFR mutations in lung cancer and PARP inhibitors for BRCA-mutated breast and ovarian cancers. This personalized approach aims to maximize treatment efficacy while minimizing adverse effects on normal cells.

Genomic profiling has also played a role in stratifying patients for immunotherapy. Certain genetic signatures, such as microsatellite instability (MSI) or high tumor mutational burden (TMB), are associated with enhanced response to immune checkpoint inhibitors (Sha *et al.*, 2020). This information guides clinicians in identifying patients who are more likely to benefit from immunotherapy, a revolutionary treatment modality that harnesses the immune system to target cancer cells.

The dynamic nature of cancer necessitates continuous monitoring of treatment response and the emergence of resistance. Genomic techniques, including liquid biopsies, allow for the non-invasive monitoring of circulating tumor DNA, enabling clinicians to assess treatment efficacy, detect minimal residual disease, and identify emerging resistance mechanisms (Maia *et al.*, 2020). This real-time feedback loop facilitates adaptive treatment strategies to optimize patient outcomes.

In conclusion, genomic medicine has emerged as a cornerstone of cancer research, providing a molecular roadmap that guides diagnostics, treatment decisions, and ongoing monitoring. The progress made in understanding the genetic basis of various cancers has fueled the development of targeted therapies, immunotherapies, and personalized treatment strategies. As genomic profiling becomes increasingly integrated into routine clinical practice, the future holds the promise of more precise and effective cancer care, ushering in an era where the genetic blueprint of each patient's cancer is leveraged for tailored and optimized therapeutic interventions (Herberts *et al.*, 2023).

3. Immunotherapy Breakthroughs

The landscape of cancer treatment has undergone a revolutionary transformation with the advent of immunotherapy. Unlike traditional approaches that directly target cancer cells, immunotherapy harnesses the power of the immune system to recognize, attack, and eliminate cancer cells (Kumar *et al.*, 2021). This paradigm shift has marked a new era in cancer research, offering novel and promising avenues for treating various malignancies.

Immunotherapy exploits the intricate machinery of the immune system, which is naturally equipped to identify and eliminate foreign invaders. Cancer cells, however, can cleverly evade detection by the immune system through various mechanisms (Schaller and Agudo, 2020). Immunotherapy seeks to overcome these evasion tactics, unleashing the full potential of the immune system to combat cancer. One of the groundbreaking developments in immunotherapy is the discovery and utilization of immune checkpoint inhibitors. Immune checkpoints are regulatory molecules that act as brakes on the immune response, preventing excessive activation and potential harm to normal tissues (Jiang *et al.*, 2021). Cancer cells often exploit these checkpoints to evade immune surveillance.

Programmed cell death protein 1 (PD-1) and its ligand PD-L1 are key players in immune checkpoint regulation. In certain cancers, tumor cells express PD-L1, which binds to PD-1 on immune cells, inhibiting their ability to attack the cancer. Immune checkpoint inhibitors, such as pembrolizumab and nivolumab, block the PD-1/PD-L1 interaction,

unleashing the immune system to recognize and attack cancer cells (Parvez *et al.*, 2023). These inhibitors have shown remarkable efficacy across various cancers, including melanoma, lung cancer, and bladder cancer.

Cytotoxic T-lymphocyte-associated protein 4 (CTLA-4) is another checkpoint molecule that downregulates immune responses. Ipilimumab, an immune checkpoint inhibitor targeting CTLA-4, has demonstrated significant success in treating melanoma. By blocking CTLA-4, this immunotherapy unleashes the immune system's cytotoxic T cells to mount a robust attack against cancer cells. Beyond immune checkpoint inhibitors, immunotherapy has witnessed advancements in adoptive cell therapies and cancer vaccines, contributing to the expanding arsenal of treatment modalities (Raghani *et al.*, 2024).

Chimeric Antigen Receptor T-cell (CAR-T) therapy is a groundbreaking approach where a patient's T cells are genetically engineered to express a receptor targeting a specific cancer antigen. This personalized therapy has shown remarkable success in treating hematological malignancies, such as certain types of leukemia and lymphoma. CAR-T cells effectively recognize and eliminate cancer cells bearing the targeted antigen, leading to durable responses and, in some cases, long-term remissions. Adoptive cell therapy also involves the extraction and expansion of tumor-infiltrating lymphocytes (TILs) from a patient's own tumor tissue (Qin *et al.*, 2021). These activated TILs are then infused back into the patient, enhancing the immune response against the cancer. This approach has shown promise in melanoma and other solid tumors. Cancer vaccines aim to stimulate the immune system to recognize and attack cancer cells. Therapeutic cancer vaccines, such as Sipuleucel-T for advanced prostate cancer, have been developed to train the immune system to target specific antigens expressed by cancer cells (Mukherjee *et al.*, 2022). While still an evolving field, cancer vaccines hold great potential in bolstering the immune response against a variety of malignancies.

The success stories of immunotherapy in treating advanced-stage cancers are compelling testaments to its transformative impact on patient outcomes. Melanoma, known for its aggressive nature, has seen significant breakthroughs with immunotherapy. Immune checkpoint inhibitors, particularly those targeting PD-1 and CTLA-4, have demonstrated durable responses and improved survival rates in patients with advanced melanoma (Carlino *et al.*, 2021). These therapies have shifted the treatment landscape, providing new hope for individuals facing previously dire prognoses. Immunotherapy has also made substantial inroads in the treatment of lung cancer, a leading cause of cancer-related mortality. PD-1/PD-L1 inhibitors, such as pembrolizumab and atezolizumab, have become standard-of-care options for certain subsets of patients with advanced non-small cell lung cancer (NSCLC) (Qu *et al.*, 2021). These therapies offer an alternative for patients who may not be suitable candidates for traditional chemotherapy.

CAR-T cell therapy has achieved remarkable success in treating hematological malignancies. In patients with relapsed or refractory B-cell acute lymphoblastic leukemia (ALL) and diffuse large B-cell lymphoma (DLBCL), CAR-T therapies like tisagenlecleucel and axicabtagene ciloleucel have demonstrated high response rates, leading to FDA approvals and offering a lifeline for patients with limited treatment options. Immunotherapy has shown promise in the treatment of cervical cancer. The FDA approval of pembrolizumab for advanced cervical cancer with disease progression on or after chemotherapy marked a significant milestone (Giudice *et al.*, 2023). This approval provides a new avenue for patients with limited therapeutic options in this challenging malignancy.

In conclusion, immunotherapy has emerged as a transformative force in cancer research, reshaping the treatment landscape and offering new avenues of hope for patients with advanced-stage cancers. The key developments in immune checkpoint inhibitors, adoptive cell therapies, and cancer vaccines underscore the dynamic progress in this field (Sharma *et al.*, 2023). The success stories witnessed in various cancers exemplify the potential of immunotherapy to redefine the standard of care and illuminate a path toward more effective, durable, and personalized cancer treatments. As research in immunotherapy continues to advance, the prospect of expanding its benefits to a broader spectrum of cancer types remains an exciting frontier in the ongoing quest for innovative cancer therapies.

4. Personalized Medicine Approaches

Cancer, with its inherent complexity and heterogeneity, has prompted a paradigm shift in treatment strategies. The conventional one-size-fits-all approach has given way to the era of personalized medicine, where treatments are tailored to the individual characteristics of each patient and their specific cancer (Kulavi *et al.*, 2021). This review explores the transformative progress in personalized medicine approaches within cancer research in the United States, focusing on the shift from generic treatments to precision therapies that leverage liquid biopsies and advanced imaging techniques for enhanced monitoring and targeted interventions.

Traditionally, cancer treatments followed a standardized approach, often guided by the tissue of origin and histological characteristics of the tumor. However, this approach did not account for the considerable genetic and molecular

diversity within and between different cancer types. Personalized medicine seeks to address this limitation by considering the unique genetic makeup of each patient's cancer.

The advent of genomic medicine has played a pivotal role in enabling personalized treatment strategies. Genomic profiling involves analyzing the genetic alterations in a patient's tumor to identify specific mutations that drive cancer growth (Chakravarty and Solit, 2021). This information allows clinicians to match patients with targeted therapies designed to inhibit the specific molecular pathways implicated in their cancer. The identification of actionable mutations has become a cornerstone of personalized cancer care.

Targeted therapies, a key component of personalized medicine, are designed to selectively interfere with specific molecules or pathways involved in the growth and survival of cancer cells (Manzari *et al.*, 2021). For instance, drugs targeting the epidermal growth factor receptor (EGFR) are used in patients with EGFR-mutant lung cancers, leading to more effective and less toxic treatments. Immunotherapy, another pillar of personalized medicine, aims to harness the body's immune system to fight cancer. The identification of specific biomarkers, such as PD-L1 expression or microsatellite instability (MSI), guides the selection of patients who are more likely to respond to immune checkpoint inhibitors (Gjoerup *et al.*, 2020). This precision allows for more effective utilization of immunotherapy, avoiding unnecessary treatments for patients unlikely to benefit.

One of the transformative advancements in personalized medicine is the emergence of liquid biopsies as a non-invasive tool for real-time monitoring of treatment responses. Liquid biopsies involve analyzing components such as circulating tumor DNA (ctDNA) or circulating tumor cells (CTCs) shed into the bloodstream, providing a dynamic snapshot of the tumor's genetic landscape.

Liquid biopsies allow for the early detection of genetic alterations associated with cancer. By detecting ctDNA or CTCs, clinicians can identify mutations, copy number variations, and other genomic changes, even before they manifest as measurable tumors. This early detection potential is particularly crucial for identifying minimal residual disease and guiding treatment decisions. In the course of treatment, liquid biopsies offer a unique opportunity to monitor the response to therapy in real-time. Changes in the levels of ctDNA or the emergence of new mutations can indicate treatment efficacy or the development of resistance (Vidal *et al.*, 2020). This dynamic monitoring allows for timely adjustments to treatment plans, optimizing therapeutic outcomes.

Liquid biopsies provide a less invasive alternative to traditional tissue biopsies. Rather than relying on repeated surgical or needle biopsies, which can be uncomfortable and carry associated risks, liquid biopsies offer a blood-based approach that is both minimally invasive and more amenable to frequent sampling (Barrie and Ferreira-Gonzalez, 2022).

In addition to molecular approaches, advanced imaging techniques play a crucial role in personalized cancer treatment, providing insights into the spatial and functional aspects of tumors.

Traditional imaging modalities like computed tomography (CT) and magnetic resonance imaging (MRI) offer anatomical details but may not capture the functional aspects of tumors. Functional imaging techniques, such as positron emission tomography (PET) and functional MRI, provide information about metabolic activity, blood flow, and tissue characteristics (Manabe *et al.*, 2020). This functional insight aids in assessing tumor behavior and response to treatment.

Radiomics involves the extraction of quantitative features from medical images, allowing for a more comprehensive analysis of tumor characteristics (Scapicchio *et al.*, 2021). Imaging biomarkers derived from radiomic analyses can provide valuable information about tumor heterogeneity, aggressiveness, and response to treatment. Integrating radiomics into personalized medicine enables a more nuanced understanding of individual tumors.

Advancements in imaging technologies have facilitated the development of image-guided therapies. Real-time imaging during procedures, such as surgery or radiation therapy, enables precise targeting of tumors while sparing healthy tissues. This level of precision enhances the efficacy of treatments and minimizes the impact on surrounding normal structures. The integration of multiple imaging modalities, such as combining PET and MRI, allows for a more comprehensive characterization of tumors (Overcast *et al.*, 2021). Multimodal imaging provides complementary information, improving diagnostic accuracy and aiding in treatment planning.

In conclusion, the progress in personalized medicine approaches within cancer research in the USA signifies a shift towards more precise, individualized, and less invasive strategies. The transition from a one-size-fits-all model to tailored treatments based on genomic insights, real-time monitoring through liquid biopsies, and advanced imaging

techniques exemplifies the commitment to optimizing patient outcomes. As research continues to unravel the complexities of cancer, personalized medicine stands at the forefront, offering a beacon of hope for more effective, targeted, and less toxic interventions in the ongoing fight against this relentless disease (Raghani *et al.*, 2024).

5. Challenges in Cancer Research: Reviewing the Progress in the USA

While significant strides have been made in cancer research, challenges persist on the path towards understanding, treating, and ultimately conquering this complex set of diseases. This review examines key challenges in cancer research in the USA, encompassing the need for increased collaboration between research institutions, the crucial importance of securing adequate funding, addressing healthcare disparities in cancer outcomes, and the ongoing hurdles in the development of effective therapies.

One major challenge in cancer research is the fragmentation of efforts among various research institutions. Each institution often pursues its own research agenda, and the lack of comprehensive collaboration can hinder the sharing of data, resources, and insights. This fragmentation can slow down the pace of discovery and limit the potential for groundbreaking advancements. Collaborative initiatives require effective mechanisms for sharing data. Standardization of data collection methods, terminology, and reporting is crucial for facilitating collaboration and ensuring that research findings are comparable across different studies (Niso *et al.*, 2022). Establishing common platforms and standards for data sharing can enhance the efficiency and impact of cancer research efforts.

Cancer is a multifaceted disease that demands an interdisciplinary approach. Collaborations between researchers from diverse fields, including genetics, immunology, oncology, and computational biology, can provide a more comprehensive understanding of cancer biology (Thomas *et al.*, 2020). Breaking down silos and fostering interdisciplinary collaboration is essential for tackling the complex challenges posed by cancer. Cancer knows no borders, and global collaboration is vital for addressing the diversity of cancer types and their prevalence worldwide. Collaborative initiatives that span international boundaries can leverage diverse expertise, resources, and patient populations, accelerating progress in cancer research. Sharing insights and resources on a global scale contributes to a more holistic understanding of cancer and enhances the potential for finding universally applicable solutions (Ginsburg *et al.*, 2021).

Adequate funding is the lifeblood of cancer research, yet researchers often face challenges in securing the necessary resources to conduct impactful studies. The demand for cutting-edge technologies, sophisticated laboratory equipment, and highly skilled personnel requires substantial financial support (Ajani *et al.*, 2024). Insufficient funding can stifle innovation and slow down the translation of research discoveries into practical clinical applications.

The landscape for research funding is highly competitive, with numerous researchers vying for limited resources. This competitiveness can create barriers for early-career investigators and hinder the pursuit of innovative, high-risk research projects. Ensuring a more equitable distribution of funding and supporting diverse research ideas is crucial for fostering creativity and addressing unmet needs in cancer research (Brown *et al.*, 2023). The long-term nature of cancer research demands stable and sustained funding. Many breakthroughs in cancer research require years, if not decades, of dedicated investigation. Fluctuations in funding levels can disrupt research continuity, impacting the progress of ongoing studies and hindering the development of effective therapies.

Adequate funding is not only necessary for basic research but also for translational research that bridges the gap between laboratory discoveries and clinical applications. Funding support for clinical trials and the implementation of research findings into patient care is crucial for ensuring that promising therapies move from the bench to the bedside (Abraham and Tisdale, 2021). Disparities in cancer outcomes often stem from unequal access to screening and early detection services. Certain populations may face barriers such as limited healthcare infrastructure, geographic isolation, or financial constraints, resulting in delayed diagnosis and reduced chances of successful treatment.

Cultural and linguistic differences can pose significant challenges in healthcare delivery. Effective communication about cancer prevention, screening, and treatment options is essential, and overcoming language barriers is crucial for ensuring that individuals from diverse backgrounds receive adequate information and care. Socioeconomic factors play a significant role in cancer outcomes. Disparities in income, education, and employment can impact access to healthcare services, adherence to treatment plans, and overall health outcomes. Addressing these socioeconomic determinants is essential for achieving equitable cancer care.

Representation in clinical trials is critical for ensuring that research findings are applicable to diverse patient populations (Niranjan *et al.*, 2020). However, minority groups are often underrepresented in clinical trials, limiting the

generalizability of study results. Efforts to increase diversity in clinical trial participation are crucial for understanding how different populations respond to treatments and interventions. The inherent heterogeneity of tumors poses a formidable challenge in the development of effective therapies. Tumors can exhibit diverse genetic and molecular profiles even within the same individual, necessitating the development of targeted therapies that address this complexity. Precision medicine approaches are crucial for tailoring treatments to the unique characteristics of each patient's cancer.

Cancer cells have a remarkable ability to adapt and develop resistance to treatment over time. Resistance mechanisms can arise due to genetic mutations, tumor microenvironment changes, or the activation of alternative survival pathways (Khalaf *et al.*, 2021). Overcoming resistance poses a significant challenge, requiring ongoing research to understand these mechanisms and develop strategies to circumvent or mitigate them.

While immunotherapy has shown remarkable success, challenges remain in understanding and overcoming resistance to these treatments. Some tumors are inherently resistant to immunotherapy, and identifying biomarkers that predict responsiveness is an ongoing challenge. Additionally, managing immune-related adverse events and optimizing combination therapies are areas of active research. The development of novel cancer therapies often comes with a high financial burden, impacting the affordability and accessibility of these treatments (Haier and Schaefers, 2022). Ensuring that groundbreaking therapies are accessible to all patients, regardless of socioeconomic status, is an ongoing challenge in cancer research and healthcare delivery.

In conclusion, reviewing the progress of cancer research in the USA reveals not only remarkable advancements but also persistent challenges that require concerted efforts to address. Increasing collaboration between research institutions, securing adequate funding, addressing healthcare disparities, and overcoming challenges in therapy development are essential elements of a comprehensive strategy to continue making strides in the fight against cancer (Winkfield *et al.*, 2021). By addressing these challenges, researchers, clinicians, policymakers, and advocates can collectively contribute to a future where the impact of cancer is minimized, and effective, equitable, and accessible treatments become a reality for all.

6. Future Directions: Reviewing the Progress of Cancer Research in the USA

As we reflect on the advancements in cancer research in the USA, it is crucial to chart a course for the future, identifying key directions that hold the potential to shape the next era of breakthroughs in understanding, diagnosing, and treating cancer. This review explores the future directions of cancer research, emphasizing the importance of interdisciplinary collaboration, translational initiatives, maintaining a patient-centered approach, and exploring potential areas for future innovation.

The future of cancer research lies in the seamless integration of diverse disciplines. Genomic insights, immunological advancements, and computational approaches can collectively unravel the complexities of cancer (Liang *et al.*, 2024). Collaborations between geneticists, immunologists, data scientists, and clinicians can lead to a more comprehensive understanding of the interplay between genetic factors, immune responses, and the dynamic nature of tumors. Integrating emerging fields like metabolomics and epigenetics into cancer research can provide deeper insights into the regulatory mechanisms influencing cancer development and progression. Understanding how metabolic alterations and epigenetic modifications contribute to cancer biology can open new avenues for targeted interventions.

The increasing complexity of genomic data requires sophisticated computational analyses. Bioinformatics and artificial intelligence (AI) play a pivotal role in extracting meaningful patterns from vast datasets, aiding in the identification of potential therapeutic targets and personalized treatment strategies (Dlamini *et al.*, 2020). The collaboration between computational scientists and biologists is crucial for harnessing the power of AI in cancer research. Cancer is not solely a biological phenomenon; it also has profound psychological and social implications. Integrating behavioral sciences, psychology, and patient advocacy into cancer research can enhance our understanding of the psychosocial aspects of cancer, improve patient support systems, and ensure that research outcomes are sensitive to the holistic needs of patients and their families.

Translational research bridges the gap between fundamental scientific discoveries and their application in clinical settings. Future efforts should prioritize strategies for accelerating the translation of basic science findings into tangible clinical benefits. Streamlining the process from bench to bedside ensures that promising therapies and interventions reach patients more rapidly. Closer collaboration between researchers and clinicians is essential for successful translational initiatives. Establishing mechanisms for continuous dialogue and collaboration can facilitate the seamless integration of research findings into clinical practice. Transdisciplinary teams that bring together researchers and

healthcare practitioners can optimize the translation of scientific knowledge into actionable clinical strategies (Thomas *et al*., 2023).

Clinical trials are essential for evaluating the efficacy and safety of novel treatments. Future initiatives should focus on improving the accessibility of clinical trials, addressing barriers such as geographic constraints, socioeconomic disparities, and underrepresentation of certain demographic groups. Innovative trial designs and virtual trial platforms can enhance participation and diversity. Real-time integration of patient data into research initiatives can expedite the identification of relevant biomarkers, treatment responses, and adverse events. Utilizing electronic health records, wearable technologies, and patient-reported outcomes can create a dynamic feedback loop that informs ongoing research and enhances the adaptability of clinical interventions (Jagannath *et al*., 2021).

The future of cancer research must continue to prioritize personalized medicine, tailoring treatment plans based on the unique characteristics of each patient's cancer. Advances in genomics, liquid biopsies, and other diagnostic tools can contribute to a more precise understanding of individual tumors, guiding the selection of targeted therapies and immunotherapies (Sivapalan *et al*., 2023). Empowering patients to actively participate in their care and decision-making processes is crucial. Future initiatives should focus on enhancing health literacy, providing accessible information, and fostering shared decision-making between healthcare professionals and patients. Engaging patients as partners in research can also contribute valuable insights into their preferences and priorities.

Beyond treatment, cancer research should prioritize the development of supportive care and survivorship programs. Addressing the long-term physical, emotional, and social consequences of cancer treatments is essential for improving the overall quality of life for cancer survivors. Integrating survivorship care into the continuum of cancer research ensures a holistic approach to patient well-being. Engaging communities in the research process is crucial for understanding diverse perspectives, addressing disparities, and ensuring that research outcomes are relevant and applicable to the broader population. Community outreach programs, educational initiatives, and partnerships with advocacy groups can facilitate a more inclusive and patient-centric research agenda (Sarah, 2023).

While immunotherapy has shown remarkable success, its full potential is yet to be realized. Future breakthroughs may involve expanding the applicability of immunotherapy to currently resistant cancers, refining combination therapies, and overcoming challenges related to immune-related adverse events. Strategies for enhancing the durability and depth of responses to immunotherapy are areas of active exploration (Liang *et al*., 2021).

Precision oncology will continue to evolve with advancements in genomic profiling, liquid biopsies, and artificial intelligence. Future breakthroughs may involve identifying rare and actionable mutations, predicting treatment responses with greater accuracy, and expanding the use of precision medicine beyond common cancer types.

Early detection remains a cornerstone for improving cancer outcomes. Future breakthroughs may involve the integration of novel technologies, such as liquid biopsies, advanced imaging modalities, and artificial intelligence, for more sensitive and specific detection of early-stage cancers (Foser *et al*., 2024). Strategies for implementing widespread and cost-effective screening approaches are crucial.

7. Recommendation

The journey of cancer research in the USA has been marked by significant achievements, reflective of the collective dedication and ingenuity of researchers, clinicians, and advocates. From the elucidation of intricate genomic landscapes to the groundbreaking developments in immunotherapy, the progress made in understanding, diagnosing, and treating cancer has been monumental.

Genomic research has unveiled the intricate genetic tapestry of cancers, paving the way for precision medicine approaches. The identification of driver mutations, the development of targeted therapies, and the integration of genomic profiling into clinical practice represent transformative achievements in tailoring treatments to the unique characteristics of each patient's cancer. The advent of immunotherapy has ushered in a new era in cancer treatment, harnessing the power of the immune system to combat malignancies. Immune checkpoint inhibitors, CAR-T cell therapies, and cancer vaccines have demonstrated unprecedented success in treating various cancers, offering renewed hope for patients with previously limited therapeutic options.

Liquid biopsies and advanced imaging techniques have emerged as valuable tools for real-time monitoring of treatment responses and enhancing the precision of cancer diagnostics. These non-invasive approaches provide insights into the dynamic nature of tumors, facilitating adaptive treatment strategies and reducing the reliance on invasive procedures.

The shift towards personalized medicine, coupled with interdisciplinary collaboration, translational initiatives, and a patient-centered approach, signifies the evolving landscape of cancer research. As we look to the future, the integration of diverse disciplines, accelerated translation of research findings, patient empowerment, and the pursuit of innovative breakthroughs are poised to shape the next chapter in the fight against cancer.

While celebrating the progress made, it is essential to acknowledge the persistent challenges that require sustained attention and collaborative efforts. Challenges such as the need for increased collaboration between research institutions, securing adequate funding, addressing healthcare disparities, and overcoming obstacles in therapy development demand a commitment to continued innovation and perseverance.

Increased collaboration between research institutions, supported by adequate funding, is fundamental to overcoming the fragmented nature of cancer research. Collaborative initiatives that span disciplines, institutions, and borders can amplify the impact of research efforts and accelerate progress towards understanding the complexities of cancer. Addressing healthcare disparities in cancer outcomes demands a multifaceted approach. By focusing on improving access to screening and early detection, addressing cultural and socioeconomic barriers, and ensuring diverse representation in clinical trials, researchers can contribute to more equitable outcomes and reduce disparities in cancer care. Ongoing challenges in the development of effective therapies, managing resistance mechanisms, and making novel treatments accessible to all underscore the need for sustained research efforts. Overcoming these challenges requires a combination of innovative scientific approaches, collaborative clinical trials, and an unwavering commitment to translating research findings into tangible patient benefits.

As we look ahead, the future for cancer patients is filled with promise and optimism. Ongoing advancements in research, fueled by the collaborative spirit of the global scientific community, hold the potential to transform the landscape of cancer care. The convergence of genomics, immunotherapy, precision medicine, and emerging technologies paints a picture of a future where individualized, effective, and less invasive treatments redefine the standard of care for cancer patients. The emphasis on interdisciplinary research fosters innovation by bringing together experts from diverse fields. Integrating genomics, immunology, computational biology, behavioral sciences, and patient advocacy enables a more comprehensive understanding of cancer and the development of holistic approaches to patient care.

Translational initiatives that bridge the gap between research and clinical application are poised to yield transformative outcomes. The seamless integration of research findings into patient care, facilitated by advancements in real-time data integration and enhanced collaboration between researchers and clinicians, ensures that discoveries are rapidly translated into tangible benefits for patients. Maintaining a patient-centered approach remains paramount in shaping the future of cancer research. Empowering patients through shared decision-making, prioritizing supportive care and survivorship programs, and engaging communities in the research process contribute to a healthcare landscape that is not only scientifically advanced but also empathetic and responsive to the diverse needs of individuals affected by cancer.

8. Conclusion

In conclusion, as we reflect on the progress of cancer research in the USA, we stand at the threshold of a promising future. The collaborative efforts of researchers, the resilience of patients, and the transformative potential of ongoing advancements position us on the brink of unprecedented breakthroughs. By addressing challenges with determination, embracing innovation, and maintaining a steadfast commitment to improving patient outcomes, the trajectory of cancer research promises to chart a course towards a future where cancer is not only better understood but also more effectively and compassionately managed.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abraham, A.A. and Tisdale, J.F., 2021. Gene therapy for sickle cell disease: moving from the bench to the bedside. *Blood, The Journal of the American Society of Hematology*, *138*(11), pp.932-941.

[2] Adamczak, B.B., Kuźnik, Z., Makles, S., Wasilewski, A. and Kosendiak, A.A., 2023, December. Physical Activity, Alcohol, and Cigarette Use in Urological Cancer Patients over Time since Diagnosis. In *Healthcare* (Vol. 12, No. 1, p. 59). MDPI.

[3] Ajani, S.N., Khobragade, P., Dhone, M., Ganguly, B., Shelke, N. and Parati, N., 2024. Advancements in Computing: Emerging Trends in Computational Science with Next-Generation Computing. *International Journal of Intelligent Systems and Applications in Engineering*, *12*(7s), pp.546-559.

[4] Barrie, E.S. and Ferreira-Gonzalez, A., 2022. Advances in Cell-Free DNA. *Advances in Molecular Pathology*, *5*(1), pp.141-148.

[5] Beltrami, A., Hilliard, A. and Green, A.L., 2022. Demographic and socioeconomic disparities in pediatric cancer in the United States: current knowledge, deepening understanding, and expanding intervention. *Cancer Epidemiology*, *76*, p.102082.

[6] Brown, S.A., Beavers, C., Bauer, B., Cheng, R.K., Berman, G., Marshall, C.H., Guha, A., Jain, P., Steward, A., DeCara, J.M. and Olaye, I.M., 2023. Advancing the care of individuals with cancer through innovation & technology: proceedings from the cardiology oncology innovation summit 2020 and 2021. *American Heart Journal Plus: Cardiology Research and Practice*, p.100354.

[7] Carlino, M.S., Larkin, J. and Long, G.V., 2021. Immune checkpoint inhibitors in melanoma. *The Lancet*, *398*(10304), pp.1002-1014.

[8] Chakravarty, D. and Solit, D.B., 2021. Clinical cancer genomic profiling. *Nature Reviews Genetics*, *22*(8), pp.483-501.

[9] Conte, F., Fiscon, G., Licursi, V., Bizzarri, D., D'Antò, T., Farina, L. and Paci, P., 2020. A paradigm shift in medicine: A comprehensive review of network-based approaches. *Biochimica et Biophysica Acta (BBA)-Gene Regulatory Mechanisms*, *1863*(6), p.194416.

[10] de Álava, E., 2024. Current challenges and practical aspects of molecular pathology for bone and soft tissue tumors. *Virchows Archiv*, pp.1-15.

[11] Dewani, D., Karwade, P. and Mahajan, K.S., 2023. Uterine Transplantation and Fertility Preservation: A Hopeful Horizon for Cancer Survivors. *Cureus*, *15*(12).

[12] Dlamini, Z., Francies, F.Z., Hull, R. and Marima, R., 2020. Artificial intelligence (AI) and big data in cancer and precision oncology. *Computational and structural biotechnology journal*, *18*, pp.2300-2311.

[13] Dujardin, P., Baginska, A.K., Urban, S. and Grüner, B.M., 2021. Unraveling tumor heterogeneity by using DNA barcoding technologies to develop personalized treatment strategies in advanced-stage PDAC. *Cancers*, *13*(16), p.4187.

[14] Elmore, L.W., Greer, S.F., Daniels, E.C., Saxe, C.C., Melner, M.H., Krawiec, G.M., Cance, W.G. and Phelps, W.C., 2021. Blueprint for cancer research: Critical gaps and opportunities. *CA: A Cancer Journal for Clinicians*, *71*(2), pp.107-139.

[15] Foser, S., Maiese, K., Digumarthy, S.R., Puig-Butille, J.A. and Rebhan, C., 2024. Looking to the Future of Early Detection in Cancer: Liquid Biopsies, Imaging, and Artificial Intelligence. *Clinical Chemistry*, *70*(1), pp.27-32.

[16] Gao, X. and Homayoonfal, M., 2023. Exploring the anti-cancer potential of Ganoderma lucidum polysaccharides (GLPs) and their versatile role in enhancing drug delivery systems: a multifaceted approach to combat cancer. *Cancer Cell International*, *23*(1), p.324.

[17] Ginsburg, O., Ashton-Prolla, P., Cantor, A., Mariosa, D. and Brennan, P., 2021. The role of genomics in global cancer prevention. *Nature Reviews Clinical Oncology*, *18*(2), pp.116-128.

[18] Giudice, E., Mirza, M.R. and Lorusso, D., 2023. Advances in the Management of Recurrent Cervical Cancer: State of the Art and Future Perspectives. *Current Oncology Reports*, *25*(11), pp.1307-1326.

[19] Gjoerup, O., Brown, C.A., Ross, J.S., Huang, R.S., Schrock, A., Creeden, J., Fabrizio, D. and Tolba, K., 2020. Identification and utilization of biomarkers to predict response to immune checkpoint inhibitors. *The AAPS Journal*, *22*, pp.1-15.

[20] Haier, J. and Schaefers, J., 2022. Economic perspective of cancer care and its consequences for vulnerable groups. *Cancers*, *14*(13), p.3158.

[21] Herberts, C., Wyatt, A.W., Nguyen, P.L. and Cheng, H.H., 2023. Genetic and Genomic Testing for Prostate Cancer: Beyond DNA Repair. *American Society of Clinical Oncology Educational Book*, *43*, p.e390384.

[22] Jagannath, S., Mikhael, J., Nadeem, O. and Raje, N., 2021. Digital health for patients with multiple myeloma: an unmet need. *JCO Clinical Cancer Informatics*, *5*, pp.1096-1105.

[23] Jiang, X., Liu, G., Li, Y. and Pan, Y., 2021. Immune checkpoint: the novel target for antitumor therapy. *Genes & diseases*, *8*(1), pp.25-37.

[24] Johnson, D., Fehrenbacher, L., Novotny, W., Scagliotti, G., Parikh, P., von Pawel, J., Travis, W., Brambilla, E., Burke, A., Marx, A. and Nicholson, A., 2020, June. Molecular diagnostics in non-small cell lung carcinoma. In *Seminars in Respiratory and Critical Care Medicine* (Vol. 41, No. 03, pp. 386-399). 333 Seventh Avenue, New York, NY 10001, USA.: Thieme Medical Publishers.

[25] Khalaf, K., Hana, D., Chou, J.T.T., Singh, C., Mackiewicz, A. and Kaczmarek, M., 2021. Aspects of the tumor microenvironment involved in immune resistance and drug resistance. *Frontiers in immunology*, *12*, p.656364.

[26] Kulavi, S., Ghosh, C., Saha, M. and Chatterjee, S., 2021. One size does not fit all: An overview of personalized treatment in cancer. *Journal of Pharmaceutical Research International*, pp.87-103.

[27] Kumar, A.R., Devan, A.R., Nair, B., Vinod, B.S. and Nath, L.R., 2021. Harnessing the immune system against cancer: current immunotherapy approaches and therapeutic targets. *Molecular Biology Reports*, pp.1-21.

[28] Liang, A., Kong, Y., Chen, Z., Qiu, Y., Wu, Y., Zhu, X. and Li, Z., 2024. Advancements and applications of single-cell multi-omics techniques in cancer research: Unveiling heterogeneity and paving the way for precision therapeutics. *Biochemistry and Biophysics Reports*, *37*, p.101589.

[29] Liang, J.L., Luo, G.F., Chen, W.H. and Zhang, X.Z., 2021. Recent advances in engineered materials for immunotherapy-involved combination cancer therapy. *Advanced Materials*, *33*(31), p.2007630.

[30] Maia, M.C., Salgia, M. and Pal, S.K., 2020. Harnessing cell-free DNA: plasma circulating tumour DNA for liquid biopsy in genitourinary cancers. *Nature Reviews Urology*, *17*(5), pp.271-291.

[31] Manabe, O., Oyama-Manabe, N. and Tamaki, N., 2020. Positron emission tomography/MRI for cardiac diseases assessment. *The British Journal of Radiology*, *93*(1113), p.20190836.

[32] Manzari, M.T., Shamay, Y., Kiguchi, H., Rosen, N., Scaltriti, M. and Heller, D.A., 2021. Targeted drug delivery strategies for precision medicines. *Nature Reviews Materials*, *6*(4), pp.351-370.

[33] Mukherjee, B., Al Hoque, A., Chakraborty, A., Chakraborty, S., Dutta, L., Dutta, D., Banerjee, S., Dhara, M. and Deepa, R.M., 2022. Recent developments in cancer vaccines: where are we?. *Nanotherapeutics in Cancer Vaccination and Challenges*, pp.29-75.

[34] Niranjan, S.J., Martin, M.Y., Fouad, M.N., Vickers, S.M., Wenzel, J.A., Cook, E.D., Konety, B.R. and Durant, R.W., 2020. Bias and stereotyping among research and clinical professionals: perspectives on minority recruitment for oncology clinical trials. *Cancer*, *126*(9), pp.1958-1968.

[35] Niso, G., Botvinik-Nezer, R., Appelhoff, S., De La Vega, A., Esteban, O., Etzel, J.A., Finc, K., Ganz, M., Gau, R., Halchenko, Y.O. and Herholz, P., 2022. Open and reproducible neuroimaging: from study inception to publication. *NeuroImage*, p.119623.

[36] Overcast, W.B., Davis, K.M., Ho, C.Y., Hutchins, G.D., Green, M.A., Graner, B.D. and Veronesi, M.C., 2021. Advanced imaging techniques for neuro-oncologic tumor diagnosis, with an emphasis on PET-MRI imaging of malignant brain tumors. *Current Oncology Reports*, *23*, pp.1-15.

[37] Parvez, A., Choudhary, F., Mudgal, P., Khan, R., Qureshi, K.A., Aspatwar, A. and Farooqi, H., 2023. PD-1 and PD-L1: architects of immune symphony and immunotherapy breakthroughs in cancer treatment. *Frontiers in Immunology*, *14*, p.1296341.

[38] Peng, F., Liao, M., Qin, R., Zhu, S., Peng, C., Fu, L., Chen, Y. and Han, B., 2022. Regulated cell death (RCD) in cancer: key pathways and targeted therapies. *Signal Transduction and Targeted Therapy*, *7*(1), p.286.

[39] Qin, S.S., Melucci, A.D., Chacon, A.C. and Prieto, P.A., 2021. Adoptive T cell therapy for solid tumors: pathway to personalized standard of care. *Cells*, *10*(4), p.808.

[40] Qu, J., Mei, Q., Liu, L., Cheng, T., Wang, P., Chen, L. and Zhou, J., 2021. The progress and challenge of anti-PD-1/PD-L1 immunotherapy in treating non-small cell lung cancer. *Therapeutic advances in medical oncology*, *13*, p.1758835921992968.

[41] Raghani, N.R., Chorawala, M.R., Mahadik, M., Patel, R.B., Prajapati, B.G. and Parekh, P.S., 2024. Revolutionizing cancer treatment: comprehensive insights into immunotherapeutic strategies. *Medical Oncology*, *41*(2), p.51.

[42] Raghani, N.R., Chorawala, M.R., Mahadik, M., Patel, R.B., Prajapati, B.G. and Parekh, P.S., 2024. Revolutionizing cancer treatment: comprehensive insights into immunotherapeutic strategies. *Medical Oncology*, *41*(2), p.51.

[43] Rai, V., Gupta, Y., Srivastava, S.P., Shukla, A., Bano, N. and Khan, S., 2023. Targeted Therapies in Cancer Treatment: Unveiling the Latest Breakthroughs and Promising Approaches. *Journal for Research in Applied Sciences and Biotechnology*, *2*(6), pp.175-183.

[44] Reyna, M.A., Haan, D., Paczkowska, M., Verbeke, L.P., Vazquez, M., Kahraman, A., Pulido-Tamayo, S., Barenboim, J., Wadi, L., Dhingra, P. and Shrestha, R., 2020. Pathway and network analysis of more than 2500 whole cancer genomes. *Nature communications*, *11*(1), p.729.

[45] Sarah, Y., 2023. The Pivotal Role of Patient Advocacy In Shaping Clinical Research And Regulatory Policies: A Comprehensive Review. *Journal Of Healthcare and Life-Science Research*, *2*(12), pp.292-305.

[46] Scapicchio, C., Gabelloni, M., Barucci, A., Cioni, D., Saba, L. and Neri, E., 2021. A deep look into radiomics. *La radiologia medica*, *126*(10), pp.1296-1311.

[47] Schaller, J. and Agudo, J., 2020. Metastatic colonization: Escaping immune surveillance. *Cancers*, *12*(11), p.3385.

[48] Sha, D., Jin, Z., Budczies, J., Kluck, K., Stenzinger, A. and Sinicrope, F.A., 2020. Tumor mutational burden as a predictive biomarker in solid tumors. *Cancer discovery*, *10*(12), pp.1808-1825.

[49] Sharma, P., Goswami, S., Raychaudhuri, D., Siddiqui, B.A., Singh, P., Nagarajan, A., Liu, J., Subudhi, S.K., Poon, C., Gant, K.L. and Herbrich, S.M., 2023. Immune checkpoint therapy—current perspectives and future directions. *Cell*, *186*(8), pp.1652-1669.

[50] Sivapalan, L., Murray, J.C., Canzoniero, J.V., Landon, B., Jackson, J., Scott, S., Lam, V., Levy, B.P., Sausen, M. and Anagnostou, V., 2023. Liquid biopsy approaches to capture tumor evolution and clinical outcomes during cancer immunotherapy. *Journal for immunotherapy of cancer*, *11*(1).

[51] Thomas, A., Roberge-Dao, J., Iqbal, M.Z., Salbach, N.M., Letts, L.J., Polatajko, H.J., Rappolt, S., Debigaré, R., Ahmed, S., Bussières, A. and Paterson, M., 2023. Developing multisectoral strategies to promote evidence-based practice in rehabilitation: findings from an end-of-grant knowledge translation symposium. *Disability and Rehabilitation*, pp.1-12.

[52] Thomas, F., Roche, B., Giraudeau, M., Hamede, R. and Ujvari, B., 2020. The interface between ecology, evolution, and cancer: more than ever a relevant research direction for both oncologists and ecologists. *Evolutionary Applications*, *13*(7), pp.1545-1549.

[53] Vidal, J., Taus, A. and Montagut, C., 2020. Dynamic treatment stratification using ctDNA. *Tumor Liquid Biopsies*, pp.263-273.

[54] Winkfield, K.M., Regnante, J.M., Miller-Sonet, E., González, E.T., Freund, K.M. and Doykos, P.M., 2021. Development of an actionable framework to address cancer care disparities in medically underserved populations in the United States: expert roundtable recommendations. *JCO Oncology Practice*, *17*(3), pp.e278-e293