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Challenging Aging: Extending Lifespan and Improving Quality of Life with Science and Technology

Menantang Penuaan: Memperpanjang Umur dan Meningkatkan Kualitas Hidup dengan Sains dan Teknologi

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ABSTRACT
The recent integration of gene therapy, cell therapy, and nanomedicine technologies has become a promising research focus in extending lifespan and improving quality of life in aging populations. This study aims to conduct a systematic review of the latest literature discussing the application of these three technologies in the context of aging. The research method used is a systematic analysis of articles selected from international databases such as PubMed, Scopus, and Web of Science, using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method as a guide. The results of the discussion show that the integration of gene therapy, cell therapy, and nanomedical technology has great potential in overcoming various aging problems and improving the quality of life in the elderly population. The implication of this research is the importance of continuing to develop integrated therapeutic approaches to respond to the challenges of aging, taking into account ethical, social and safety aspects in their application in clinical practice and the development of appropriate health policies.
Keywords: Gene therapy, Cell therapy, Nanomedical technology, Aging, Quality of life, Elderly population.

ABSTRAK
Integrasi terbaru antara terapi gen, terapi sel, dan teknologi nanomedis telah menjadi fokus penelitian yang menjanjikan dalam memperpanjang usia hidup dan meningkatkan kualitas hidup pada populasi lanjut usia. Penelitian ini bertujuan untuk melakukan tinjauan sistematik terhadap literatur terbaru yang membahas aplikasi ketiga teknologi tersebut dalam konteks penuaan. Metode penelitian yang digunakan adalah analisis sistematis terhadap artikel-artikel yang dipilih dari database internasional seperti PubMed, Scopus, dan Web of Science, dengan menggunakan metode PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) sebagai panduan. Hasil pembahasan menunjukkan bahwa integrasi terapi gen, terapi sel, dan teknologi nanomedis memiliki potensi besar dalam mengatasi berbagai masalah penuaan dan meningkatkan kualitas hidup pada populasi lanjut usia. Implikasi penelitian ini adalah pentingnya terus mengembangkan pendekatan terapi yang terintegrasi untuk merespons tantangan penuaan, dengan memperhatikan aspek etis, sosial, dan keamanan dalam penerapannya di praktik klinis serta pembangunan kebijakan kesehatan yang sesuai.
Kata kunci: Terapi gen, Terapi sel, Teknologi nanomedis, Penuaan, Kualitas hidup, Populasi lanjut usia.

1. Introduction

The pursuit of challenging aging and extending lifespan while improving the quality of life has become a focal point for researchers and scientists. Understanding the mechanisms of aging and identifying common patterns of changes at the genetic, protein, and posttranslational levels across various tissues is a challenging yet crucial task for aging researchers (Mkrtchyan et al., 2020). The burden of aging on society has led to significant investments in high technology industries to harness anti-aging and regenerative modalities (Garmany et al., 2021). Furthermore, there are different mindsets regarding the challenges and potentials of human longevity, including essentialist, medicalist, and stoicist mindsets, which influence the approach to addressing aging (Lang & Rupprecht, 2019).

ging is a biological process characterized by the gradual degradation of physiological functions, leading to increased morbidity and mortality (Li et al., 2021). Anti-aging research aims to improve lifespan, reverse the impacts of diseases, and develop regenerative medicine to combat cell death and accelerate aging progression (A, 2023). Studies on centenarians in East China have revealed enriched taxa among the gut microbiota, shedding light on the potential role of gut flora in longevity (Wang et al., 2019). In addition, gut microbe-metabolite profiles have been associated with microbial pathways of longevity, indicating a potential link between specific gut bacteria and longevity-related metabolic pathways (Zhang, 2023).

Aging is intricately linked to degenerative diseases such as atherosclerosis, osteoporosis, and Alzheimer's disease, highlighting the need for a deeper understanding of the mechanisms and therapeutic effects of oxidative stress and stem cell-based materials in skin aging (Qian et al., 2023). Metabolomics studies have identified signature metabolites associated with longevity, providing insights into the intrinsic interaction of age, plasma signature metabolites, and nutrient intake in long-lived populations (Li et al., 2022). Novel optical coherence tomography-based methods have been developed for in vitro anti-aging skin analysis, offering alternative strategies for preclinical research on skin aging (Min et al., 2023).

The identification of new aging markers and the standardization of markers and methods are crucial for advancing biological age research (Li et al., 2023). The insulin signaling pathway has been implicated in controlling the longevity phenomenon, emphasizing the importance of understanding the molecular mechanisms underlying aging (Haroon et al., 2022). To encourage participation in aging research, programs such as Advancing Diversity in Aging Research (ADAR) have been sponsored to support undergraduate research education in aging and human development (Roberts et al., 2022). In conclusion, the multidimensional nature of aging and longevity research encompasses biological, genetic, microbiological, and societal aspects. Understanding the mechanisms of aging, identifying potential interventions, and fostering diversity in aging research are essential for addressing the challenges and opportunities associated with extending lifespan and improving the quality of life.

The field of anti-aging technology encompasses a wide range of research areas, including cellular aging, regenerative medicine, and skin care. Studies have investigated the causes of cellular aging, genes involved in aging, and diseases associated with aging (A, 2023). Additionally, there is a focus on developing anti-aging therapeutics, such as caloric restriction mimetics, which have shown potential in prolonging lifespan (Bibyk et al., 2021). Furthermore, advancements in cosmeceuticals have led to the development of novel carrier systems for delivering anti-aging compounds, demonstrating the multifunctional and effective nature of these products (Morganti & Coltelli, 2019). In the realm of skin care, innovative technologies, such as three-dimensional fringe projection-based devices, have been validated for skin surface mapping and the assessment of anti-aging products (Shaiek et al., 2023). Moreover, the use of growth factor serums in combination with hydradermabrasion treatments has shown efficacy in targeting signs of skin aging (Huang, 2024). Stem cell-based materials have also emerged as a promising avenue for mitigating oxidative stress and addressing skin aging (Qian et al., 2023). in addition, formulations containing retinol and acetyl hexapeptide-1 have demonstrated improvements in photoaged facial skin, highlighting the potential of supramolecular technologies in anti-aging interventions (Ye et al., 2023). Overall, these diverse research efforts underscore the interdisciplinary nature of anti-aging technology and its potential to revolutionize healthcare and skincare practices.

This phenomenon is a global challenge that is becoming increasingly significant as life expectancy increases throughout the world. Extending lifespan and improving quality of life in aging populations has become a major focus in scientific research and technological development. In this context, the recent integration of gene therapy, cell therapy, and nanomedical technologies has emerged as a promising innovative approach.

However, although much research has been conducted in this area, there is still a lack of comprehensive literature on the integration of these three technologies and their impact on quality of life in the elderly population.

Therefore, the aim of this study was to systematically investigate these latest integrations and understand how they can contribute to improving the quality of life in older people. The research question posed in this context is: "How does the latest integration between gene therapy, cell therapy and nanomedicine technology improve the quality of life in the elderly population?". This research is unique in approaching the integration of these three technologies in an integrated manner, with the aim of providing an in-depth understanding of their potential and challenges in improving the quality of life in older people. It is hoped that this research contribution will provide new insights that will benefit the development of anti-aging therapies and more effective health care for the aging population globally.

2. Research Methods

The methodology stage of this research, scientific articles were collected from various trusted international databases, including PubMed, Scopus, and Web of Science. This process is carried out using keywords that are relevant and related to the research topic, such as "aging", "gene therapy", "cell therapy", "nanomedicine", and so on. The number of articles obtained was then identified, and the selection process was carried out in accordance with previously determined inclusion and exclusion criteria. Inclusion criteria include the presence of articles in English, publication in peer-reviewed journals, relevance to the research topic, and availability of the full text of the article. On the other hand, exclusion criteria include articles that are not relevant to the research topic, publications in abstract form, and articles that do not meet established quality standards. The use of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method was the main guide in preparing this literature review. The PRISMA method provides a systematic and transparent framework for presenting research findings from various sources in a structured and comprehensive way. Thus, the use of the PRISMA method is expected to increase the validity and reliability of the results of this literature review and ensure the accuracy and objectivity of the preparation process.

3. Results and Discussions

3.1. Understanding Gene Therapy in the Context of Aging

Gene therapy has emerged as a promising approach for addressing aging-related disorders. Recent studies have highlighted the potential of gene therapy in antagonizing aging and aging-related diseases (Wang et al., 2021). Understanding the genetic mechanisms involved in the aging process is crucial for developing effective therapies for aging-related diseases (Mohamed et al., 2022). Research has provided a comprehensive overview of genetic aspects of aging, longevity, and their association with aging-related pathologies, emphasizing the potential of innovative medicine, including gene therapy (Sabriuly, 2023). Furthermore, gene therapy has been shown to induce beneficial effects on epigenetic mechanisms associated with aging and frailty in aged mice, suggesting potential implications for future human therapies to prevent frailty (Giuliani et al., 2023).

In addition to genetic aspects, the interrelationships among metabolism, proteins, genes, and the immune system have been investigated to provide a systematic understanding of the aging process, offering insights for potential anti-aging strategies (Tian, 2022). However, it is essential to consider the ethical, social, and safety aspects of gene therapy, as reports of severe adverse events have raised concerns among researchers and the public (Li et al., 2023). Moreover, gene therapy targeting hematopoietic stem cells has shown progress in inherited diseases, highlighting the challenges and advancements in this field (Cavazzana et al., 2019).

Furthermore, gene therapy has been reported to delay aging in mouse models, emphasizing its potential in addressing age-related cardiovascular diseases (Fossel et al., 2022).

The transfer of human genes associated with exceptional longevity has shown promising therapeutic effects on atherosclerosis and inflammation, indicating the potential of gene therapy in addressing age-related conditions (Puca et al., 2019). Additionally, gene therapy with a longevity-associated variant has been found to reduce senescence in various conditions, further supporting its potential in addressing age-related diseases (Puca et al., 2022).

In summary, recent research has demonstrated the potential of gene therapy in addressing aging-related disorders, offering insights into the genetic mechanisms of aging and the development of innovative therapeutic approaches.

In recent years, gene therapy has emerged as a promising approach in the fight against aging, with a focus on improving the health and quality of life of the elderly population. Several studies have explored various gene therapy strategies aimed at addressing age-related diseases and the aging process itself. Zeng et al. (2020) conducted a transcriptome analysis to understand the differences between healthy and common aging, shedding light on their connection with age-related diseases. This study provides valuable insights into the molecular mechanisms underlying healthy aging and age-related diseases.

Furthermore, Mammadzada et al. (2019) discussed the role of hypoxia-inducible factors in neovascular age-related macular degeneration from a gene therapy perspective. Understanding the molecular pathways involved in age-related macular degeneration is crucial for developing effective gene therapy interventions for this condition. Additionally, Flotte et al. (2022) presented a study on AAV gene therapy for Tay-Sachs disease, demonstrating the potential of gene therapy in stabilizing the progression of this devastating condition. This study highlights the clinical implications of gene therapy in addressing age-related genetic diseases.

Moreover, Li et al. (2021) provided insights into the centrality of histone modifications in osteogenic differentiation, offering a potential therapeutic target for osteogenic differentiation-related diseases. This study contributes to the understanding of gene therapy applications in age-related bone disorders. Furthermore, Sun et al. (2022) and Jiapaer et al. (2022) explored the potential roles of m6A RNA methylation and RNA modifications in aging-related diseases, respectively. These studies underscore the significance of RNA-based gene therapy approaches in addressing age-related pathologies.

In addition, Gharipour et al. (2021) discussed the relationship between epigenetic modifications and cardiovascular disease in older adults, emphasizing the impact of lifestyle and environmental factors on epigenetic mechanisms. This study provides valuable insights into the potential of epigenetics-based gene therapy for age-related cardiovascular conditions. Finally, Dolcetti et al. (2022) investigated the effects of IGF1 gene therapy on delaying reproductive senescence in middle-aged female rats, shedding light on the potential of gene therapy in modulating age-related physiological changes. This study offers valuable implications for gene therapy interventions targeting age-related reproductive senescence.

3.2. Cell Therapy as an Anti-Aging Therapeutic Approach

Stem cell therapy has emerged as a promising approach in anti-aging therapeutics due to its rapid and efficient therapeutic effect, precision delivery, and safety (Deng et al., 2022). The theory of aging and its molecular mechanism, as well as the strategies for removing senescent cells and improving the aging environment, have been reviewed, elucidating cutting-edge anti-aging therapies, including stem cell therapy (Tian, 2022). Additionally, evidence suggests that mammalian health and lifespan can be extended through stem cell therapy, adding to the limited list of successful anti-aging/life-extending interventions (Guderyon et al., 2020). Furthermore, the influence of organismal aging on mesenchymal stem cell therapy has been recognized as a potential impediment, highlighting the importance of understanding the impact of aging on the efficacy of stem cell therapy (Lee, 2020). Moreover, the regenerative potential of mesenchymal stem cells has been a focus, as cell-based therapies often require high cell numbers for clinical applications, necessitating in vitro expansion of cells

(Choudhery, 2021).

In the context of immune therapies against aging, a better understanding of Treg cell function may aid in the development of new immune therapies against aging (Deng et al., 2021). Furthermore, cancer immunotherapy, including CAR T-cell therapy and myeloma immunotherapy, has shown promise in various malignancies, contributing to the broader spectrum of anti-aging therapeutic approaches (Zhu et al., 2021; Liu et al., 2021; Bishop, 2019; Casey & Nakamura, 2021). Additionally, immunological changes during anti-TNF-α therapy have been studied, shedding light on the correlations with treatment outcomes in specific conditions (Chen et al., 2021). In summary, the references from 2019-2024 provide comprehensive insights into the potential of stem cell therapy and immune therapies as anti-aging therapeutic approaches, emphasizing the need for further research and development in this field.

To understand the potential of cell therapy in mitigating the aging process and optimizing health in the elderly population, it is essential to synthesize findings from various studies. The regenerative potential of cells and their ability to modulate inflammatory responses are key aspects of cell therapy applications (Bhartiya et al., 2023). For instance, studies have suggested that aging can be reversed by partial reprogramming in vivo, indicating the potential of cell therapy in addressing age-related issues (Bhartiya et al., 2023). However, the evaluation of cell therapy effectiveness extends beyond biological aspects to clinical implications, including safety, efficacy, and the availability of necessary technologies for implementation.

Furthermore, the application of cell therapy in elderly populations requires consideration of specific health conditions. For example, the rise in the incidence of inflammatory bowel disease among the aging population has led to an increased number of elderly patients with this condition, emphasizing the importance of understanding the clinical spectrum of elderly-onset inflammatory bowel disease (Gupta et al., 2023). Additionally, factors associated with adverse events to antiretroviral therapy in adults and elderly individuals living with HIV need to be considered when evaluating the safety and efficacy of cell therapy in elderly populations (Sales et al., 2021).

Moreover, the successful application of cell therapy in elderly individuals may involve addressing age-related conditions such as depression. Integrating therapy, including cognitive restructuring and relaxation interventions, has shown promise in reducing the onset of depression in older adults, highlighting the potential of comprehensive interventions in addressing age-related mental health issues (Pradana et al., 2021). In conclusion, synthesizing findings from studies on cell therapy applications in aging and elderly populations is crucial for understanding the potential of cell therapy in overcoming the aging process and improving health in the elderly. This synthesis provides a basis for the development of more effective cell therapy interventions tailored to the specific needs of elderly individuals.

3.3. The Role of Nanomedical Technology in Improving the Quality of Life in the Elderly Population

Nanomedical technology has the potential to significantly improve the quality of life in the elderly population by addressing various health challenges. The ethical and legal challenges associated with nanomedical innovations have been recognized, particularly in disease detection, diagnosis, and treatment (Wasti et al., 2023). Additionally, the interconnected biological processes of cancer and aging highlight the importance of avoiding over-treatment to ensure an optimal quality of life (Berben et al., 2021). Psychological distress, government strategies, and social distancing have been found to influence the quality of life during outbreaks, emphasizing the need for holistic approaches to elderly care (Khan et al., 2021). Furthermore, the potential of nanotechnology in diagnostic devices, drug delivery systems, and energy storage technologies underscores its role in advancing nanomedical applications (Haddad, 2024).

The history and future developments of electrospinning have paved the way for the fabrication of fluorescent nanospheres, which hold promise for precise biomedicine in advanced nanomedical technologies, including local bioimaging, light diagnostics, therapy, optogenetics, and health monitoring (Keirouz et al., 2023; Gallo et al., 2021). Nanomaterial-based catalysts have also emerged as a key area of interest in nanomedical technologies, showcasing the rapid advancements in nanotechnology and materials science (Zhao et al., 2020). Moreover, the use of artificial intelligence in nanomedical applications, particularly in diagnosing and treating ailments through implanted intelligent nanosystems, presents a novel approach to enhancing elderly care (El-atty et al., 2022).

In the context of the elderly population, factors such as housing, living-related factors, and social support have been identified as crucial determinants of quality of life (Duan & Juan, 2021; Tarkar, 2021). Additionally, the impact of atopic dermatitis, diabetes mellitus, and cancer on the quality of life underscores the need for tailored nanomedical interventions to address these specific health challenges in the elderly (Berben et al., 2021; Hund et al., 2022; Sethi et al., 2022). Furthermore, the role of physical activities and social participation in enhancing elders' quality of life has been emphasized, highlighting the importance of holistic approaches to elderly care (Chen et al., 2021). In conclusion, nanomedical technology holds great promise in improving the quality of life in the elderly population by addressing various health challenges and ethical considerations. By leveraging the advancements in nanotechnology, materials science, and artificial intelligence, tailored nanomedical interventions can be developed to enhance the well-being of the elderly.

The application of nanomedical technology in improving the quality of life in aging populations is a burgeoning area of research. Nanomedical technologies, such as drug nanoparticles, nanosensors, and nanotherapy, have shown promise in addressing health conditions associated with aging. For instance, demonstrated the potential of nano-RBCs in photodynamic therapy for addressing cancer-induced hypoxia (Shao et al., 2019). Additionally, highlighted the use of plasmonic nanorattles for in situ imaging of bacterial metabolism, showcasing the diverse applications of nanotechnology in understanding physiological processes (Marchi et al., 2021). Furthermore, the study by emphasized the role of population aging in promoting technological innovation, which is conducive to high-quality economic development (Gao, 2023).

The advantages of nanomedical technology over conventional approaches have been a subject of interest. illustrated the fabrication of fluorescent nanospheres from PEGylated tetratyrosine nanofibers, demonstrating the potential of nanotechnology in creating advanced materials with unique properties (Gallo et al., 2021). Moreover, investigated the changes in NMR characteristics of corona aging silicone rubber materials, shedding light on the material science aspects of nanomedicine (Bi et al., 2020). These studies collectively underscore the potential and challenges in applying nanomedical technology to improve the quality of life in older adults globally.

In addition, the ethical and legal challenges associated with nanomedical innovations have been recognized. conducted a scoping review on the ethical and legal challenges in nanomedical innovations, emphasizing the need to address these issues as nanomedicine advances (Wasti et al., 2023). Furthermore, the effect of the older population on public health spending has been highlighted as an urgent challenge for advanced economies, as discussed by (Navarro-García & Sarría-Santamera, 2022). In conclusion, the research on the role of nanomedical technology in improving the quality of life in aging populations is multifaceted, encompassing technological advancements, ethical considerations, and economic implications. As the field continues to evolve, addressing the potential and challenges of nanomedical technology is crucial for harnessing its benefits in enhancing the well-being of older individuals.

3.4. Recent Integration between Gene Therapy, Cell Therapy, and Nanomedical Technology

Recent years have witnessed a significant integration between gene therapy, cell therapy, and nanomedical technology, leading to advancements in regenerative medicine, clinical trials, and genetic enhancement. Cell and gene therapy products are rapidly being integrated into mainstream medicine (O'Sullivan et al., 2019). Nanomedicine has offered better nanodelivery systems for gene therapy, enhancing its efficacy and precision (Giakoumettis & Sgouros, 2021). The understanding of structures, mechanisms, clinical applications, and off-target activities of genome editing systems through integration of gene sequencing, clinical transomics, and single-cell biomedicine has been proposed as a critical part of clinical precision medicine strategies and multidisciplinary therapy strategies (Wang & Wang, 2021).

Moreover, the development of a blockchain-based supply chain system for advanced therapies, including cell therapy and gene therapy, is forecasted to grow at a compound annual growth rate of 22% from 2018 to 2022 (Lam et al., 2020). Additionally, significant efforts have been made to integrate 6G and nanonetwork-based molecular communication for modeling targeted drug delivery, indicating a shift towards more advanced and precise therapeutic approaches (El-atty et al., 2022). Furthermore, recent nanomedical applications for cardiac regeneration have highlighted the versatility of nanomaterials combined with the newest molecular biology discoveries to advance cardiac regeneration therapies (Cassani et al., 2020).

In the context of gene therapy, recent advancements and challenges associated with gene therapy have been discussed, including hematopoietic stem cell therapy, CAR-T cell therapy, and CRISPR/Cas9 gene therapy (Aggarwal & Mittal, 2022). The advancement of genome engineering technologies has facilitated gene therapy for the prevention and management of intractable diseases, offering promising prospects for the treatment of various genetic disorders (Belete, 2021). Additionally, the conceptual techniques in gene therapy, such as DNA recombination technology, treatment with synthetic oligonucleotides, and delivery of messenger Ribonucleic acid (mRNA), have shown potential for precise and targeted therapeutic interventions (Sari et al., 2021).

The translation of nanomedical developments into clinical application is receiving increasing interest, with actively targeted nanoparticles being studied as a diagnostic tool and as a selective drug carriage specifically to cancerous sites (Sudri et al., 2021). Furthermore, the development of new genetic, cellular, and recombinant protein therapies has shown promise, with revertant mosaicism (RM) emerging as a unique gene and cell therapy phenomenon with potential applications in genetic enhancement and gene therapy (Meyer-Mueller et al., 2022). In conclusion, the recent integration between gene therapy, cell therapy, and nanomedical technology has led to significant advancements in regenerative medicine, precision medicine, and targeted therapeutic interventions. The combination of advanced therapies with nanomedical technologies and precision medicine strategies holds great promise for the future of medical treatment.

Recent research has explored the potential integration of gene therapy, cell therapy, and nanomedicine in addressing various medical challenges. Nanomedicine has been investigated for directing neuronal differentiation of neural stem cells for stroke therapy, indicating its potential in neurological conditions (Lin et al., 2021). Additionally, the scope of photothermal therapy-based nanomedicines in preclinical models of colorectal cancer has been reviewed, demonstrating the multifunctionality of nanomedicines in delivering combinations of therapeutics and imaging agents (Khot et al., 2019). Furthermore, the transient expression of an adenine base editor has shown promise in correcting genetic mutations associated with progeria syndrome, highlighting the potential of gene therapy in addressing genetic disorders (Whisenant et al., 2022). The current status of gene therapy for cancer treatment has been reviewed, indicating advancements in the development of safe and effective treatments for complex disorders (Belete, 2021). Moreover, brain-targeting nanomedicines have been developed for potent combinatorial therapy of glioblastoma, showcasing the potential of integrating nanomedicine with RNAi therapy for aggressive brain tumors (Zhang et al., 2022). Additionally, the design of stimuli-responsive crosslinked nanomedicines for cancer treatment has been explored, indicating advancements in the development of nanomedicines that respond to specific stimuli for targeted therapy (Xue et al., 2022).

These studies collectively demonstrate the potential of integrating gene therapy, cell therapy, and nanomedicine in addressing a wide range of medical conditions, from neurological disorders to cancer. The findings provide insights into the advancements and challenges in implementing these integrated technologies, paving the way for more effective and personalized health interventions for aging populations.

4. Conclusion

Recent research highlights the integration of gene therapy, cell therapy, and nanomedical technologies as an innovative approach to addressing various medical challenges. Advances in regenerative, clinical, and genetic fields have driven the integration of these three technologies into conventional medicine. The development of cell and gene therapy products has quickly become part of mainstream medicine. Nanomedical technology has offered better nanodelivery systems for gene therapy, increasing its effectiveness and precision. Understanding the structure, mechanisms, clinical applications, and off-target activities of genome editing systems through the integration of gene sequencing, clinical transomics, and single-cell biomedicine has been proposed as an important part of multidisciplinary clinical and therapeutic strategies. Additionally, the development of blockchain-based supply chain systems for advanced therapies, including cell therapy and gene therapy, is predicted to grow at a compound annual growth rate of 22% from 2018 to 2022. Great efforts have been made to integrate 6G-based technologies and nanonetwork molecular communications to model targeted drug delivery, indicating a shift towards more sophisticated and precise therapeutic approaches. Furthermore, recent nanomedicine applications for cardiac regeneration have highlighted the flexibility of nanomaterials with recent molecular biology discoveries to advance cardiac regeneration therapies.

In the context of gene therapy, recent advances and challenges associated with gene therapy have been discussed, including hematopoietic stem cell therapy, CAR-T cell therapy, and CRISPR/Cas9 gene therapy. Advances in genome engineering technology have facilitated gene therapy for the prevention and treatment of intractable diseases, offering promising prospects for the treatment of various genetic disorders. Additionally, conceptual techniques in gene therapy, such as DNA recombination technology, treatment with synthetic oligonucleotides, and mRNA delivery, have demonstrated potential for precision and targeted therapeutic interventions. The application of nanomedicine in the treatment of cancer with actively targeted nanomaterials has been investigated as a diagnostic tool and as a selective drug carrier specifically to cancer-affected sites. Furthermore, the development of new gene, cellular, and recombinant protein therapies has shown promising results, with revertant mosaicism (RM) emerging as a unique phenomenon in gene and cell therapy with potential applications in genetic repair and gene therapy.

Overall, the recent integration of gene therapy, cell therapy, and nanomedicine technologies has resulted in significant advances in regenerative medicine, precision medicine, and targeted therapeutic interventions. The combination of advanced therapies with nanomedicine technology and precision medicine strategies has great potential for the future of medical treatment.

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