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Unraveling the Mystique: Augmented Insights into Stem Cell Biology and Nanogenomic Engineering

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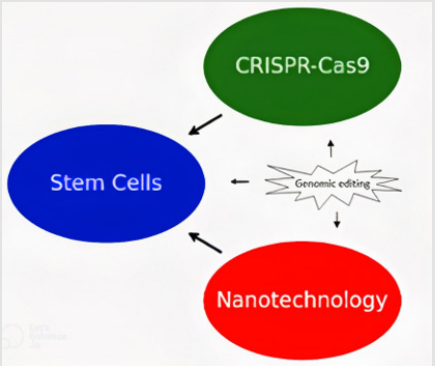
ABSTRACT

This review explores the revolutionary integration of stem cell biology, nanogenomic engineering, and CRISPR-Cas9 technology in advancing regenerative medicine and therapeutic interventions. Stem cells, with their inherent capabilities for differentiation and self-renewal, stand at the forefront of novel treatments for a myriad of diseases. The advent of nanogenomic engineering has further enhanced the precision and efficiency of stem cell manipulation, enabling targeted gene editing and therapy delivery. CRISPR-Cas9 technology plays a pivotal role in this integration, offering unparalleled specificity in genome editing. This synergy promises to revolutionize medical approaches by enabling precise and individualized treatments, underscoring the necessity of addressing ethical, safety, and regulatory challenges to fully realize the potential of these technologies in improving patient outcomes. The review emphasizes the importance of multidisciplinary research in pushing the boundaries of medical science, aiming fundamentally to transform healthcare and patient care paradigms (Graphical Abstract).



Graphical Abstract: This graphical abstract includes representations for stem cells, CRISPR-Cas9 genome editing, and nanotechnology, highlighting their interconnected roles in advancing regenerative medicine and therapeutic interventions.

Keywords: Regenerative Medicine; Stem Cell Biology; Nanogenomic Engineering; Crispr-Cas9 Genome Editing; Precision Therapeutics

Introduction

Introduction to the Revolutionary Impact of Stem Cell Biology

Stem cell biology represents a transformative shift in medical science, revolutionizing our understanding and treatment methodologies for a myriad of diseases [1-3]. Stem cells, with their unique propensity to differentiate into various cell types, have become the linchpin of regenerative medicine [4]. This offers unprecedented prospects for tissue and organ repair and potential remedies for diseases once deemed incurable [5]. Notably, the advent of induced pluripotent stem cells (iPSCs) has marked a significant advancement by mitigating immune rejection and ethical dilemmas, while the integration of nanotechnology has refined the precision and effectiveness of stem cell-based therapies [6]. The influence of stem cell biology extends beyond conventional therapeutic boundaries, particularly in immunology, where engineered immune cells are designed to target and eliminate cancer, and in tissue engineering, which aspires to cultivate lab-grown organs [7-9]. Despite the promise, the path is fraught with challenges, including ethical quandaries, genomic stability, and potential tumorigenicity [10]. These complexities necessitate comprehensive research and strict regulatory oversight. Moreover, the intricate interplay between stem cells and the immune system presents both opportunities and obstacles, underscoring the need for ensuring the safety and efficacy of these therapies [11,12].

The Quest for Understanding: Deciphering the Molecular and Genomic Foundations of Stem Cells: Embarking on a quest to decode the molecular and genomic complexities of stem cells is akin to exploring the fundamental codes of life [13,14]. This journey, at the intersection of regenerative medicine, immunology, and nanotechnology, seeks to understand the signaling pathways, transcription factors, and epigenetic mechanisms that dictates stem cell behavior and potential [15]. At the molecular level, stem cells are paradigms of biological finesse, boasting remarkable self-renewal capabilities and the ability to differentiate into a diverse spectrum of specialized cells [16]. Central to this process are the signaling pathways, transcription factors, and epigenetic modifications that collectively direct cellular fate [17]. Advanced techniques like CRISPR-Cas9 and RNA sequencing have become instrumental in mapping the transcriptomic landscape, illuminating the molecular switches crucial for stem cell behavior [18].

Concurrently, the genomic landscape of stem cells presents a vast reservoir of information, revealing regulatory networks essential for maintaining pluripotency and guiding differentiation [19]. Addressing issues of genomic instability and mutations is critical for the secure application of stem cell therapies [20]. The use of sophisticated tools like single-cell genomics is imperative for detailed monitoring and understanding [21]. The incorporation of nanotechnology has catalyzed a paradigm shift in stem cell research, providing precise tools to manipulate and understand cells at both molecular and genomic scales [22]. Nanoscale technologies enable the targeted delivery of genetic material, real-time tracking of cellular dynamics, and the potential to modulate cell behavior through external stimuli [23,24].

The Molecular Architecture of Stem Cells

Architectural Complexity of Stem Cells: Balancing Self-Renewal and Differentiation: The molecular architecture of stem cells epitomizes the intricate balance between self-renewal and differentiation, fundamental to their therapeutic potential [25]. These dual properties define stem cells' unique role in regenerative medicine. Self-renewal is orchestrated by a complex interplay of signaling pathways such as Wnt, Notch, and Hedgehog, and transcription factors such as Oct4, Sox2, and Nanog [26]. These elements meticulously maintain the equilibrium between proliferation and pluripotency [27]. Conversely, differentiation is the transformative journey from stem cells to specialized cell types, driven by a synergy of extrinsic signals and intrinsic epigenetic alterations [28]. This process intricately directs specific gene expression patterns and cell fates, pivotal for regenerative applications. The advent of nanotechnology has refined this domain, providing unprecedented control over the cellular microenvironment and behavior, enhancing our ability to direct these fundamental processes with precision [29].

Epigenetic Mastery in Stem Cell Fate and Function: Epigenetics emerges as a cardinal regulator in stem cells, dictating gene expression beyond the genetic code [30]. Modifications like DNA methylation and histone alteration, alongside non-coding RNA dynamics, are instrumental in maintaining pluripotency and orchestrating differentiation [31]. DNA methylation serves as a pivotal regulatory sentinel, either repressing or activating gene expression, thereby guiding gene expression patterns that are critical for establishing stem cell identity and determining lineage commitment. Concurrently, histone modifications, along with the actions of non-coding RNAs such as microRNAs and long non-coding RNAs, intricately modulate the epigenetic landscape. This modulation ensures a delicate equilibrium is maintained between the processes of self-renewal and differentiation [32,33]. Emerging technologies such as CRISPR/Cas9-mediated epigenome editing and advanced sequencing methods are revolutionizing our capacity to map and manipulate this epigenetic terrain. Despite the potential, challenges in specificity, stability, and ethical implications persist, necessitating a nuanced approach to harnessing these mechanisms for clinical application [34-36].

Unraveling Transcriptomic Diversity: Elucidating Cellular Potentials: Exploring the transcriptomic diversity of stem cells offers a profound window into their cellular potentials and underlying molecular narratives [37]. This diversity, captured through advanced single-cell transcriptomic analyses, reveals the intricate regulatory networks and intermediate states pivotal for understanding pluripotency and lineage specificity. Key transcription factors and a plethora of non-coding RNAs contribute to a complex transcriptomic land-

scape, governing stem cell fate and function [38-41]. These insights are crucial for regenerative medicine as they provide a foundation for enhancing disease modeling, facilitating the identification of potential drug targets, and informing the development of therapeutic cell engineering strategies. By integrating transcriptomic data with other omics layers, such as genomics, proteomics, and metabolomics, we can achieve a holistic understanding of stem cell biology. This integration reveals novel regulatory circuits and pathways essential for stem cell function and differentiation. However, the challenge lies in deciphering the vast and complex data sets to extract meaningful insights, which necessitates the application of sophisticated computational strategies and analytical tools.

Nanogenomic Engineering a Convergence of Nanotechnology and Genomic Engineering for Precision Medicine

Nanogenomic engineering is an interdisciplinary field that melds nanotechnology with genomic engineering to manipulate and edit the genome at the nanoscale level. This innovative approach employs nanoscale tools and devices to precisely target and modify genetic sequences, facilitating advanced applications in gene therapy, precision medicine, and synthetic biology. Through the integration of nanotechnology's unparalleled precision and the vast potential for genomic modifications, nanogenomic engineering aspires to revolutionize our capacity to understand, diagnose, and treat genetic disorders. Additionally, it aims to engineer biological systems for novel functionalities.

CRISPR-Cas9: Catalyzing a Revolution in Genome Editing: Nanogenomic engineering, a pioneering domain at the nexus of nanotechnology and genomics, has ushered in a new era of medical innovation with the advent of CRISPR-Cas9 [42]. This technology, renowned for its precision and versatility, has reshaped the landscape of genome editing, opening novel pathways for gene therapy and the potential eradication of genetic diseases. CRISPR-Cas9's ability to accurately target and modify specific genomic sequences has shifted the therapeutic paradigm from symptomatic management to the potential for targeted, curative interventions [43-46]. Nanotechnology plays a crucial role in augmenting the delivery and specificity of CRISPR-Cas9 gene editing systems, a pivotal advancement in genetic engineering. Nanocarriers, which are minute vehicles designed at the nanoscale, serve to transport CRISPR-Cas9 components directly to specific cells or tissues. This targeted delivery system optimizes gene editing efficiency by ensuring that the gene-editing tools reach their intended destinations within the body more effectively. Additionally, nanocarriers help in reducing off-target effects—a significant concern in gene editing—by enhancing the precision with which these tools edit the genome, thus mitigating unintended modifications [47-50]. However, the profound capabilities of this technology necessitate a comprehensive ethical and regulatory framework to ensure its safe and equitable application. As research progresses, the potential of nanogenomic engineering continues to expand, promising a future of precision medicine tailored to individual genetic profiles.

Precision and Potentials: Advancing Nanogenomic Engineering in Stem Cell Manipulation: Nanogenomic engineering represents a frontier in stem cell research, combining the precision of nanotechnology with the transformative potential of genomic engineering. Techniques such as CRISPR-Cas9 have revolutionized our capacity to edit the genome with unprecedented accuracy, offering new insights into the genetic underpinnings of stem cell pluripotency and differentiation [51-53]. This precision enables the correction of genetic defects and the introduction of beneficial alterations, significantly advancing the potential for targeted therapies. Nanocarriers play a crucial role in this paradigm, enhancing the targeted (drugs) delivery and monitoring of genomic editing tools [54-56]. Despite the advancements, this field navigates a landscape fraught with ethical and safety challenges. The pursuit of a holistic understanding of stem cell biology through an integrated multi-omics approach promises to transform our capacity for personalized and effective medical treatments, fundamentally altering our understanding of life's fundamental units [57-60].

Navigating Challenges and Ethical Considerations in Nanogenomic Engineering: The expansion of nanogenomic engineering brings a spectrum of challenges and ethical considerations. Technical challenges include ensuring precision, mitigating off-target effects, and addressing the toxicity of nanocarriers. Ethically, the ability to alter genomes raises critical questions regarding consent, privacy, and the implications of heritable modifications [61]. Establishing robust ethical guidelines and fostering public discourse is essential in navigating these complexities [62,63]. The integration of this field with emerging technologies such as artificial intelligence and big data analytics introduces new possibilities and complexities. Cultivating a culture of responsible innovation is crucial, ensuring that the advancement of nanogenomic engineering is not only scientifically progressive but also ethically sound and socially beneficial [64-66]. This approach will guide the field towards realizing its full potential in a manner that is responsible and advantageous to society.

Single-Cell Genomics: Dissecting the Complex Tapestry of Life

The Power of Single-Cell Resolution: Unveiling the Intricacies of Cellular Functions and States: Single-cell genomics, a trailblazing field in contemporary biology, provides profound insights into the nuanced functions and states of individual cells, previously masked by bulk analyses [67]. By characterizing the genomic, transcriptomic, and epigenomic landscapes at an unprecedented single-cell resolution, this approach reveals cellular heterogeneity and dynamics critical for understanding development, disease, and therapeutic outcomes [68-70]. Technological innovations in high-throughput sequencing and microfluidics have significantly expanded the capabilities of single-cell analyses, enabling large-scale, detailed studies that were previously unimaginable. These advancements have revolutionized our understanding of cellular diversity and the mechanisms underlying various diseases by allowing us to examine the genomic and tran-

scriptomic profiles of individual cells in their native environments. In the fields of regenerative medicine and complex disease research, single-cell genomics has become indispensable for pinpointing disease-associated cells, uncovering novel biomarkers, and refining stem cell-based therapies with unprecedented precision. Despite these advances, the challenges of managing and interpreting massive datasets, coupled with ethical considerations surrounding the use of genetic information, necessitate the development of advanced bioinformatics tools and the establishment of rigorous ethical frameworks to ensure responsible use of this powerful technology [71-73].

Exploring Cellular Heterogeneity and Dynamic Responses in Stem Cell Populations: Single-cell genomics has revolutionized stem cell research by enabling the dissection of cellular heterogeneity and dynamic responses at an unparalleled resolution [68,74]. This technology characterizes diverse cellular states within stem cell niches, shedding light on differentiation pathways and tissue functions [75]. The enhanced understanding of signaling networks and adaptive mechanisms through individual cell tracking informs the optimization of stem cell cultures and therapies [76]. As the field advances, it faces ethical and analytical challenges, including consent and privacy issues and the complexity of data interpretation [70,77-79]. Future prospects involve integrating single-cell genomics with multi-omics approaches, providing a comprehensive understanding of stem cell biology and unlocking new therapeutic avenues in regenerative medicine.

Implications for Disease Modeling and Regenerative Medicine: Single-cell genomics holds transformative implications for disease modeling and regenerative medicine, offering insights into cellular mechanisms and tissue regeneration processes [80]. In disease modeling, it identifies diverse cellular signatures, contributing to an in-depth understanding of disease mechanisms and the development of targeted therapies [81]. In regenerative medicine, it elucidates gene expression patterns and signaling pathways, enhancing stem cell therapy development and tissue regeneration strategies [82].

Pathways to Personalized Therapeutics

3.5.1.Bench to Bedside: Translating Molecular Insights into Clinical Realities: The trajectory of personalized therapeutics represents a fundamental shift in medical treatment, pivoting toward a model that is acutely attuned to the individual nuances of patients, propelled by molecular medicine, genomics, and nanotechnology [83]. This paradigm is revolutionizing the translational journey from bench to bedside, as detailed molecular insights guide the development of targeted clinical applications. The ability to discern intricate genetic mutations and biomolecular interactions informs the pinpointing of precise intervention targets. Single-cell genomics, by offering a granular view of cellular heterogeneity, unveils novel therapeutic targets, advancing disease understanding and treatment strategies [84-87]. Patient-specific stem cell insights and nanotechnology-driven drug delivery systems are critical in this revolution, enhancing the precision and reducing the systemic side effects of therapeutic interventions [88-90]. This molecularly informed approach necessitates a multifaceted translational process, underscored by interdisciplinary collaboration, yet is encumbered by ethical, regulatory, and implementation challenges [91]. The future of personalized medicine is a mosaic of molecular insights, technological advancements, and a nuanced understanding of individual patient profiles, promising a new epoch of tailored, effective, and accessible medical treatment.

Tailoring Regenerative Protocols to Individual Genetic Profiles: The advent of personalized therapeutics in regenerative medicine represents a transformative shift from one-size-fits-all remedies to customized strategies meticulously aligned with individual genetic blueprints [92]. This approach leverages the power of molecular medicine, single-cell genomics, and nanotechnology, aligning regenerative protocols with patients' unique genetic, cellular, and molecular signatures. Advancements in single-cell genomics provide an unprecedented understanding of genetic diversity, enabling the prediction and customization of therapies for optimized efficacy and minimized adverse effects [93-97]. The integration of patient-derived stem cells and precision nanocarriers stands as a pinnacle in therapy personalization, promising enhanced treatment efficacy and safety. However, the journey from bench to bedside is fraught with challenges, including ensuring the robustness of tailored treatments and addressing ethical and regulatory considerations. The horizon of personalized regenerative medicine is expansive, promising a future where treatments are not only disease-specific but also patient-specific, fundamentally altering the landscape of medical science and healthcare [98-101].

Overcoming Safety, Efficacy, and Regulatory Hurdles in Personalized Therapeutics: The ascent of personalized therapeutics heralds a new era of targeted and effective medical interventions, yet it is beset with significant safety, efficacy, and regulatory challenges. Ensuring safety in personalized treatments requires a deep understanding of individual biological profiles, leveraging molecular medicine and single-cell genomics to navigate the complex biological pathways unique to each patient. The role of nanotechnology in enhancing precision and mitigating toxicity is paramount, yet it demands stringent validation through comprehensive testing and monitoring [102-105]. Assessing the efficacy of personalized interventions necessitates robust methodologies capable of evaluating treatment outcomes across diverse genetic and environmental landscapes. Regulatory frameworks, too, must evolve to accommodate the unique aspects of personalized medicine, fostering international collaboration and standardization. The trajectory of personalized therapeutics is one of promise and complexity, with the integration of advanced technologies and systems biology poised to refine and revolutionize patient care, marking a new paradigm in healthcare and medical science [106-109].

Ethical and Biosafety Paradigms in Cutting-Edge Biomedical Research

Navigating the Ethical Terrain: Balancing Innovation and Moral Imperatives: The ethical landscape in biomedical research, particularly within the realms of stem cells, genomics, and regenerative medicine, requires a balanced approach that aligns rapid innovation with moral imperatives. The ethical framework guiding this field must offer comprehensive guidance to stakeholders, ensuring scientific exploration adheres to the highest ethical standards [110, 111]. Central to ethical discourse are issues such as informed consent, privacy, and moral considerations surrounding human embryos, especially with the potential for genetic enhancement and designer traits [112]. Developing robust biosafety and biosecurity measures is crucial for managing risks associated with genetic manipulation and biohazard containment [113, 114]. Engagement with the public and policymaking processes is essential to foster understanding, trust, and regulations that are ethically sound and resonate with diverse societal values [115]. International cooperation is pivotal in harmonizing ethical standards, biosafety, and biosecurity protocols, ensuring global benefits and respect for cultural diversity [116]. As biomedical research advances, ethical and safety paradigms must also evolve, requiring ongoing adaptation, reflection, and dialogue.

Ensuring Biosafety Rigor: The Cornerstone of Responsible Research: Rigorous biosafety standards are essential in the rapidly advancing domains of stem cell research, genomics, and regenerative medicine [97,117]. The establishment of comprehensive safety protocols addresses the unique risks inherent in biological material handling [118]. Risk assessment and management, together with fostering a culture of safety consciousness among researchers, are fundamental to preemptive and preventive safety strategies [119-121]. Regular monitoring, reporting, and the international standardization of biosafety protocols ensure consistency and reliability in research practices [122]. As the field progresses, biosafety paradigms must remain dynamic and responsive, adapting to new challenges and technologies through continuous research, evaluation, and community commitment [123,124].

Public Engagement and Policy Development: Steering the Future of Stem Cell Research: Proactive public engagement and informed policy development are crucial for guiding the future of stem cell research and therapy [125]. Effective communication strategies are key to demystifying the complexities of this field, building public trust, and shaping ethical and policy frameworks [126]. Policy development must address sourcing, consent, distribution, and long-term implications, such as genetic privacy, while integrating ethical and safety considerations [127-129]. International collaboration is vital for ethical standardization and ensuring global access to therapies [130]. Adaptable public engagement strategies and agile policy frameworks are paramount in responding to scientific advancements and societal shifts [131,132]. A proactive, informed approach ensures that stem cell research progresses with both innovation and moral integrity, realizing its potential in a responsible and beneficial manner [133].

Envisioning the Future: Transformative Trajectories in Stem Cell Research and Regenerative Medicine

The Horizon of Stem Cell Research: At the Brink of Revolutionary Breakthroughs: As we stand on the precipice of transformative breakthroughs, stem cell research is poised to redefine the medical and scientific landscapes. This horizon is illuminated by emerging trends and cutting-edge technologies that are converging to propel significant advancements. The refinement of stem cell applications in regenerative medicine is leading to enhanced treatment efficacies for a multitude of conditions [95,134,135]. The development of organoids and advances in single-cell genomics are providing profound insights, heralding a new era of personalized therapeutics [136-138]. However, the evolution of this field necessitates parallel advancements in ethical, social, and regulatory frameworks, ensuring that progress is underpinned by ethical integrity and international cooperation [139,140]. The future beckons with the promise of transformative medical advancements, contingent upon our ability to navigate the complex interplay of innovation, ethics, and societal impact [141,142].

Synergizing Molecular Biology and Genomics for Advanced Diagnostics and Therapeutics: The synergy between molecular biology and genomics is forging a future of advanced, precise, and personalized diagnostic and therapeutic strategies [143,144]. This evolution is characterized by a shift from broad disease categorizations to individualized molecular profiles, enhancing the sensitivity and specificity of diagnostics [145,146]. Therapeutic strategies are undergoing a radical transformation, with the integration of single-cell genomics and nanotechnology playing pivotal roles [85]. These advances are accompanied by ethical considerations and societal implications, necessitating ongoing dialogue and international collaboration to ensure responsible advancements [147,148]. The future of diagnostics and therapeutics promises unprecedented precision and personalization, reshaping healthcare and heralding a new era of medical excellence [149-152].

Conclusion

Envisioning a future where advancements in stem cell biology, nanogenomics, and CRISPR-Cas9 technology drive significant breakthroughs in medical science, it is crucial to address the accompanying ethical, safety, and regulatory challenges. Doing so will fully realize the potential of these technologies in personalized therapeutics and regenerative medicine, thereby transforming healthcare and improving patient outcomes.

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Core Tip

There is a lot of research about integrating stem cells and nanotechnology for therapy that uses CRISPR-Cas 9. However, this is a new insight and innovation in nanogenomic engineering applications integrated into stem cells for regenerative medicine. Furthermore, these innovations are feasible to fundamentally alter medical approaches and enhance human health.

Footnotes

Conflict-of-Interest Statement

There is no conflict of interest.

Author Contributions

Dito Anurogo conceived the idea for the manuscript, reviewed the literature and drafted the manuscript.

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References

1. Anurogo D (2023) The Art of Nanoimmunobiotechnomedicine in Stem Cells and Gene Editing. J Biomed Res Environ Sci Journal (4): 1348-1369.
2. Sarkar A, Saha S, Paul A, Maji A, Roy P, et al. (2021) Understanding stem cells and its pivotal role in regenerative medicine. Life Sci 273: 119270.
3. Nadeem M, M Naeem (2023) The Biology of the Future. Cosmic Journal of Biology 2.
4. Li J, Luo W, Xiao C, Zhao J, Xiang C, et al. (2023) Recent advances in endogenous neural stem/Cheppaleprogenitor cell manipulation for spinal cord injury repair. Theranostics 13: 3966-3987.
5. Eskandar K (2023) Revolutionizing biotechnology and bioengineering: unleashing the power of innovation. J Appl Biotechnol Bioeng 10 (3): 81-88.
6. Aboul-Soud MAM, Alzahrani AJ, Mahmoud A (2021) Induced Pluripotent Stem Cells (iPSCs)-Roles in Regenerative Therapies, Disease Modelling and Drug Screening. Cells 10.
7. Aguilar LE (2022) Biomaterial Science: Anatomy and Physiology Aspects. Walter de Gruyter GmbH & Co KG.
8. Li YR, Dunn ZS, Zhou Y, Lee D, Yang L, et al. (2021) Development of Stem Cell-Derived Immune Cells for Off-the-Shelf Cancer Immunotherapies. Cells 10.
9. Choi Y, Lee HK, Choi KC (2023) Engineered adult stem cells: a promising tool for anti-cancer therapy. BMB Rep 56: 71-77.
10. Park TY, Leblanc P, Kim KS (2023) Current Status and Future Perspectives on Stem Cell-Based Therapies for Parkinson's Disease. J Mov Disord 16(1): 22-41.
11. Anurogo D, Budi P, Thi Ngo MH, Huang YH, Pawitan J, et al. (2021) Cell and Gene Therapy for Anemia: Hematopoietic Stem Cells and Gene Editing. Int J Mol Sci 22(12).
12. Abubakar M, Masood MF, Javed I, Adil H, Faraz MA, et al. (2023) Unlocking the Mysteries, Bridging the Gap, and Unveiling the Multifaceted Potential of Stem Cell Therapy for Cardiac Tissue Regeneration: A Narrative Review of Current Literature, Ethical Challenges, and Future Perspectives. Cureus 15: e41533.
13. Brittoa M, Jayarajan D (2023) Unravelling the Molecular Symphony: Investigating Gene Expression at the Biochemical Level. Eur Chem Bull 12: 2799-2810.
14. Green ED, Gunter C, Biesecker LG, Di Francesco V, Easter CL, et al. (2020) Strategic vision for improving human health at The Forefront of Genomics. Nature 586: 683-692.
15. Alshangiti DM, El-Damhougy TK, Zaher A, Madani M, Mohamady Ghobashy M, et al. (2023) Revolutionizing biomedicine: advancements, applications, and prospects of nanocomposite macromolecular carbohydrate-based hydrogel biomaterials: a review. RSC Adv 13: 35251-35291.
16. Luo Q, Li H, Shan W, Wei C, Long Y et al. (2021) Specific Blood Cells Derived from Pluripotent Stem Cells: An Emerging Field with Great Potential in Clinical Cell Therapy. Stem Cells Int.
17. Tan SYX, Zhang J, Tee WW (2022) Epigenetic Regulation of Inflammatory Signaling and Inflammation-Induced Cancer. Front Cell Dev Biol 10: 931493.
18. Worthington AK, Forsberg EC (2022) A CRISPR view of hematopoietic stem cells: Moving innovative bioengineering into the clinic. Am J Hematol 97: 1226-1235.
19. Guan J, Wang G, Wang J, Zhang Z, Fu Y, et al. (2022) Chemical reprogramming of human somatic cells to pluripotent stem cells. Nature 605: 325-331.
20. Gonzalez PEA (2022) A Multilevel Approach to the Causes of Genetic Instability in Stem Cells. Handbook of Stem Cell Therapy, pp. 1445-1498.
21. Luecken MD, Büttner M, Chaichoompu K, Danese A, Interlandi M, et al. (2022) Benchmarking atlas-level data integration in single-cell genomics. Nat Methods 19: 41-50.
22. Sinha A, Simnani FZ, Singh D, Nandi A, Choudhury A, et al. (2022) The translational paradigm of nanobiomaterials: Biological chemistry to modern applications. Mater Today Bio 17: 100463.
23. Ringaci A, Yaremenko AV, Shevchenko KG, Zvereva SD, Nikitin MP, et al. (2021) Metal-organic frameworks for simultaneous gene and small molecule delivery *in vitro* and *in vivo*. Chem Eng J 418.
24. Elnathan R, Barbato MG, Guo X, Mariano A, Wang Z, et al. (2022) Biointerface design for vertical nanoprobes. Nat Rev Mater 7: 953-973.
25. Ho MSH, Ho MSH, Librach C (2022) Therapeutic potential of induced pluripotent stem cell-derived extracellular vesicles: Quo Vadis? Terra incognito. In book: Current Topics in iPSCs Technology.
26. Ervin EH, French R, Chang CH, Pauklin S (2022) Inside the stemness engine: Mechanistic links between deregulated transcription factors and stemness in cancer. Semin Cancer Biol 87: 48-83.
27. Hu W, Shi J, Lv W, Jia X, Ariga K, et al. (2022) Regulation of stem cell fate and function by using bioactive materials with nanoarchitectonics for regenerative medicine. Sci Technol Adv Mater 23: 393-412.
28. Verona F, Pantina VD, Modica C, Lo Iacono M, D'Accardo C, et al. (2022) Targeting epigenetic alterations in cancer stem cells. Front Mol Med 2.
29. Chehelgerdi M, Chehelgerdi M, Allela OQB, Pecho RDC, Jayasankar N, et al. (2023) nanotechnology to improve targeted cancer treatment: overcoming hurdles in its clinical implementation. Mol Cancer 22: 169.
30. Szukiewicz D (2022) Epigenetic regulation and T-cell responses in endometriosis - something other than autoimmunity. Front Immunol 13: 943839.
31. Vargas LN, Silveira MM, Franco MM (2023) Epigenetic Reprogramming and Somatic Cell Nuclear Transfer. Methods Mol Biol 2647: 37-58.

32. Baral I, Varghese, PC, Dutta D (2022) Epigenetics as "conductor" in "orchestra" of pluripotent states. Cell Tissue Res 390: 141-172.

33. Griazeva ED, Fedoseeva DM, Radion EI, Ershov PV, Meshkov IO, et al. (2023) Current Approaches to Epigenetic Therapy. Epigenomes 7: 23.

34. Goell JH, Hilton IB (2021) CRISPR/Cas-Based Epigenome Editing: Advances, Applications, and Clinical Utility. Trends Biotechnol 39: 678-691.

35. Ansari I, Chaturvedi A, Chitkara D, Singh S (2021) CRISPR/Cas mediated epigenome editing for cancer therapy. Semin Cancer Biol 83: 570-583.

36. Zhang D, Wang G, Yu X, Wei T, Farbiak L, et al. (2022) Enhancing CRISPR/Cas gene editing through modulating cellular mechanical properties for cancer therapy. Nat Nanotechnol 17: 777-787.

37. Umeche IJ, Olaniyan MF (2023) Exosomes: emerging biomarkers unveiling cellular mysteries—a narrative review. J Bio-X Res Journal 6: 104-115.

38. Wang L, Hu S, Zhou B (2022) Deciphering Cardiac Biology and Disease by Single-Cell Transcriptomic Profiling. Biomolecules 12: 566.

39. Wu J, Izpisua Belmonte JC (2017) Stem Cells: A Renaissance in Human Biology Research. Cell 165: 1572-1585.

40. Ramos TAR, Urquiza-Zurich S, Kim SY, Gillette TG, Hill JA, et al. (2023) Single-cell transcriptional landscape of long non-coding RNAs orchestrating mouse heart development. Cell Death Dis 14: 841.

41. Kim DH, Marinov GK, Pepke S, Singer ZS, He P, et al. (2015) Single-cell transcriptome analysis reveals dynamic changes in lncRNA expression during reprogramming. Cell Stem Cell 16: 88-101.

42. Chowdhry R, Lu SZ, Lee S, Godhulayyagari S, Ebrahimi SB, et al. (2023) Enhancing CRISPR/Cas systems with nanotechnology. Trends Biotechnol 41: 1549-1564.

43. Alhakamy NA, Curiel DT, Berkland CJ (2021) The era of gene therapy: from preclinical development to clinical application. Drug Discov Today 26: 1602-1619.

44. Xu X, Liu C, Wang Y, Koivisto O, Zhou J (2021) Nanotechnology-based delivery of CRISPR/Cas9 for cancer treatment. Adv Drug Deliv Rev 176: 113891.

45. Deng H, Huang W, Zhang Z (2019) Nanotechnology based CRISPR/Cas9 system delivery for genome editing: Progress and prospect. Nano Res 12: 2437-2450.

46. Ansori ANM, Antonius Y, Susilo RJK, Hayaza S, Kharisma VD (2023) Application of CRISPR-Cas9 genome editing technology in various fields: A review. Narra J 3: e184.

47. Aghamiri S, Talaei S, Ghavidel AA, Zandsalimi F, Masoumi S, et al. (2020) Nanoparticles-mediated CRISPR/Cas9 delivery: Recent advances in cancer treatment. J Drug Deliv Sci Technol 56: 101533.

48. Chen F, Alphonse M, Liu Q (2019) Strategies for nonviral nanoparticle-based delivery of CRISPR/Cas9 therapeutics. Wiley Interdiscip Rev Nanomed Nanobiotechnol 12: e1609.

49. Chen C, Zhong W, Du S, Li Y, Zeng Y, et al. (2022) Intelligent nanotherapeutic strategies for the delivery of CRISPR system. Acta Pharm Sin B.

50. Jacob EM, Borah A, Sakthi Kumar D (2022) CRISPR/Cas9 Nano-delivery Approaches for Targeted Gene Therapy. In: Barabadi H, Mostafavi E, Saravanan M (Eds.)., Pharmaceutical Nanobiotechnology for Targeted Therapy. Nanotechnology in the Life Sciences.

51. De Masi C, Spitalieri P, Murdocca M, Novelli G, Sangiuolo F, et al. (2020) Application of CRISPR/Cas9 to human-induced pluripotent stem cells: from gene editing to drug discovery. Hum Genomics 14: 25.

52. Hendriks D, Clevers H, Artegiani B (2021) CRISPR-Cas Tools and Their Application in Genetic Engineering of Human Stem Cells and Organoids. Cell Stem Cell 27: 705-731.

53. Mattiello L, Rütgers M, Sua-Rojas MF, Tavares R, Soares JS, et al. (2022) Molecular and Computational Strategies to Increase the Efficiency of CRISPR-Based Techniques. Front Plant Sci 13: 868027.

54. Bhaskar S, Tian F, Stoeger T, Kreyling W, de la Fuente JM, et al. (2010) Multifunctional Nanocarriers for diagnostics, drug delivery and targeted treatment across blood-brain barrier: perspectives on tracking and neuroimaging. Part Fibre Toxicol 7: 3.

55. Akhter MH, Rizwanullah M, Ahmad J, Ahsan MJ, Mujtaba MA (2017) Nanocarriers in advanced drug targeting: setting novel paradigm in cancer therapeutics. Artificial Cells, Nanomedicine, and Biotechnology 46: 873-884.

56. Vargason AM, Anselmo AC, Mitragotri S (2021) The evolution of commercial drug delivery technologies. Nat Biomed Eng 5: 951-67.

57. Sebastião MJ, Serra M, Gomes-Alves P, Alves PM (2021) Stem cells characterization: OMICS reinforcing analytics. Curr Opin Biotechnol 71: 175-81.

58. Li Y, Ma L, Wu D, Chen G (2021) Advances in bulk and single-cell multi-omics approaches for systems biology and precision medicine. Brief Bioinform 22: 6189773.

59. Santiago-Rodriguez TM, Hollister EB (2021) Multi 'omic data integration: A review of concepts, considerations, and approaches. Semin Perinatol 45: 151456.

60. Miao Z, Humphreys BD, McMahon AP, Kim J (2021) Multi-omics integration in the age of million single-cell data. Nat Rev Nephrol 17: 710-724.

61. Coller BS (2019) Ethics of Human Genome Editing. Annu Rev Med 70: 289-305.

62. (2017) National Academies of Sciences, Engineering, and Medicine; National Academy of Medicine. Human genome editing: science, ethics, and governance. National Academies Press.

63. Cohen IG, Farahany NA, Greely HT, Shacha C (2021) Consumer genetic technologies: ethical and legal considerations. Cambridge University Press.

64. Soltani M, Moradi Kashkooli F, Souri M, Zare Harofte S, Harati T, et al. (2021) Enhancing Clinical Translation of Cancer Using Nanoinformatics. Cancers (Basel) 13.

65. Konstantopoulos G, Koumoulos EP, Charitidis CA (2022) Digital Innovation Enabled Nanomaterial Manufacturing; Machine Learning Strategies and Green Perspectives. Nanomaterials 12.

66. Chapski DJ, Vondriska TM (2021) Taking Data Science to Heart: Next Scale of Gene Regulation. Curr Cardiol Rep 23: 46.

67. Zimmer M (2023) The Conversation on Biotechnology (Critical Conversations). Johns Hopkins University Press.

68. Shema E, Bernstein BE, Buenrostro JD (2019) Single-cell and single-molecule epigenomics to uncover genome regulation at unprecedented resolution. Nat Genet Nat Genet 51: 19-25.

69. Baysoy A, Bai Z, Satija R, Fan R (2023) The technological landscape and applications of single-cell multi-omics. Nat Rev Mol Cell Biol 24: 695-713.

70. Lei Y, Tang R, Xu J, Wang W, Zhang B, et al. (2021) Applications of single-cell sequencing in cancer research: progress and perspectives. J Hematol Oncol 14: 91.

71. Mu Q, Chen Y, Wang J (2019) Deciphering Brain Complexity Using Single-cell Sequencing. Genomics Proteomics Bioinformatics 17: 344-366.

72. Mereu E, Lafzi A, Moutinho C, Ziegenhain C, McCarthy DJ, et al. (2020) Benchmarking single-cell RNA-sequencing protocols for cell atlas projects. Nat Biotechnol 38: 747-55.

73. Rajewsky N, Almouzni G, Gorski1 SA, Aerts S, Amit I, et al. (2020) The Life Time initiative: Towards cell-based medicine in Europe. Nature 587: 377-386.

74. Tanay A, Regev A (2017) Scaling single-cell genomics from phenomenology to mechanism. Nature 541: 331-338.

75. Chatterjee C, Schertl P, Frommer M, Ludwig-Husemann A, Mohra A, et al. (2021) Rebuilding the hematopoietic stem cell niche: Recent developments and future prospects. Acta Biomater 132: 129-148.

76. Liu G, David BT, Trawczynski M, Fessler RG (2020) Advances in Pluripotent Stem Cells: History, Mechanisms, Technologies, and Applications. Stem Cell Rev Rep 16: 3-32.

77. Fanelli S, Pratici L, Salvatore FP, Donelli CC, Zangrandi A, et al. (2022) Big data analysis for decision-making processes: challenges and opportunities for the management of health-care organizations. MRR.

78. Gibson G (2022) Perspectives on rigor and reproducibility in single cell genomics. PLoS Genet 18: e1010210.

79. Alrefaei AF, Hawsawi YM, Almaleki D, Alafif T, Alzahrani FA, et al. (2022) Genetic data sharing and artificial intelligence in the era of personalized medicine based on a cross-sectional analysis of the Saudi human genome program. Sci Rep 12: 1405.

80. Wen L, Li G, Huang T, Geng W, Pei H, et al. (2022) Single-cell technologies: From research to application. Innovation (NY) 3: 100342.

81. Ding J, Sharon N, Bar-Joseph Z (2022) Temporal modelling using single-cell transcriptomics. Nat Rev Genet 23: 355-368.

82. Sreenivasan VKA, Balachandran S, Spielmann M (2022) The role of single-cell genomics in human genetics. J Med Genet 59: 827-839.

83. Bizzarri M, Fedeli V, Monti N, Cucina A, Jalouli M, et al. (2021) Personalization of medical treatments in oncology: time for rethinking the disease concept to improve individual outcomes. EPMA J, p. 1-14.

84. Lim J, Chin V, Fairfax K, Moutinho C, Suan D, et al. (2023) Transitioning single-cell genomics into the clinic. Nat Rev Genet 10.

85. Zhu Y, Ouyang Z, Du H, Wang M, Wang J, et al. (2022) New opportunities and challenges of natural products research: When target identification meets single-cell multiomics. Acta Pharm Sin B 12: 4011-4039.

86. Griswold M, Henegan J, Blackshear C, Windham BG, Mosley T, et al. (2022) Finding Yourself: Personalized Medicine, Data Science, And Interactive Visualizations. Innov Aging.

87. Forbes AN, Xu D, Cohen S, Pancholi P, Khurana E, et al. (2022) Discovery of novel therapeutic targets in cancer using patient-specific gene regulatory networks. BioRxiv.

88. Yetisgin AA, Cetinel S, Zuvin M, Kosar A, Kutlu O, et al, (2020) Therapeutic Nanoparticles and Their Targeted Delivery Applications. Molecules 25.

89. Sim S, Wong NK (2021) Nanotechnology and its use in imaging and drug delivery (Review). Biomed Rep 14: 42.

90. Joshi S, Allabun S, Ojo S, Alqahtani MS, Shukla PK, et al. (2023) Enhanced Drug Delivery System Using Mesenchymal Stem Cells and Membrane-Coated Nanoparticles. Molecules 28.

91. Maybee C, Gasson S, Bruce CS, Somerville M (2022) Faces of informed research: Enabling research collaboration. JIL.

92. Altyar AE, Sayed AE, Abdeen A, Piscopo M, Mousa SA, et al. (2023) Future regenerative medicine developments and their therapeutic applications. Biomed pharmacother.

93. Lightner AL, Chan T (2021) Precision regenerative medicine. Stem Cell Res Ther 12: 39.

94. Alzate-Correa D, Lawrence WR, Salazar-Puerta A, Higuita-Castro N, Gallego-Perez D, et al. Nanotechnology-Driven Cell-Based Therapies in Regenerative Medicine. AAPS J 24: 43.

95. Mukherjee S, Yadav G, Kumar R (2021) Recent trends in stem cell-based therapies and applications of artificial intelligence in regenerative medicine. World J Stem Cells 13: 521-541.

96. Dilip Kumar S, Aashabharathi M, KarthigaDevi G, Subbaiya R, Saravanan M, et al. (2021) Insights of CRISPR-Cas systems in stem cells: progress in regenerative medicine. Mol Biol Rep 49: 657-673.

97. Manzari MT, Shamay Y, Kiguchi H, Rosen N, Scaltriti M, et al. (2021) Targeted drug delivery strategies for precision medicines. Nat Rev Mater 6: 351-370.

98. Li J, Zeng H, Li L, Yang Q, He L, et al. (2023) Advanced Generation Therapeutics: Biomimetic Nanodelivery System for Tumor Immunotherapy. ACS Nano 17: 24593-24618.

99. Singh AV, Chandrasekar V, Janapareddy P, Mathews DE, Laux P et al. (2021) Emerging Application of Nanorobotics and Artificial Intelligence to Cross the BBB: Advances in Design, Controlled Maneuvering, and Targeting of the Barriers. ACS Chem Neurosci 12: 1835-1853.

100. Hasan A (2017) Tissue Engineering for Artificial Organs. WILEY-VCH Verlag GmbH & Co.

101. Van Berlo D, Nguyen VV, Gkouzioti V, Leineweber K, Verhaar MC (2021) Stem cells, organoids, and organ-on-a-chip models for personalized *in vitro* drug testing. Current Opinion in Toxicology 28: 7-14.

102. Groenland SL, Verheijen RB, Joerger M, Mathijssen RHJ, Sparreboom A, et al. (2021) Precision Dosing of Targeted Therapies is Ready for Prime Time. Clin Cancer Res 27: 6644-6652.

103. Domingues C, Santos A, Alvarez-Lorenzo C, Concheiro A, Jarak I, et al. (2022) Where Is Nano Today and Where Is It Headed? A Review of Nanomedicine and the Dilemma of Nanotoxicology. ACS Nano 16: 9994-10041.

104. Pucciarelli D, Lu BY, Zlobec I, DiStasio M Beyond the Lab and Into the Hospital: An Outlook on the Clinical Utility of Spatial Omics Technologies.

105. Allen GM, Lim WA (2022) Rethinking cancer targeting strategies in the era of smart cell therapeutics. Nat Rev Cancer 22: 693-702.

106. Beccia F, Hoxhaj I, Castagna C, Strohäker T, Cadeddu C, et al. (2022) An overview of Personalized Medicine landscape and policies in the European Union. Eur J Public Health 32: 844-851.

107. Heath A, Pechlivanoglou P (2022) Prioritizing Research in an Era of Personalized Medicine: The Potential Value of Unexplained Heterogeneity. Med Decis Making 42: 649-660.

108. Fosse V, Oldoni E, Bietrix F, Budillon A, Daskalopoulos EP, et al. (2023) Recommendations for robust and reproducible preclinical research in personalised medicine. BMC Med 21: 14.

109. Aguilera-Cobos L, García-Sanz P, Rosario-Lozano MP, Claros MG, Blasco-Amaro JA, et al. (2023) An innovative framework to determine the implementation level of personalized medicine: A systematic review. Front Public Health 11: 1039688.

110. Burton SD, Kiladi M, Morrison M, Prainsack B (2022) Responsible Personalised Medicine. Responsible personalised medicine: Exploring the ethical, legal, social, political and economic issues of manufacturing, distribution, access and reimbursement. A Report by the Future Targeted Healthcare Manufacturing Hub.

111. Morrison M, B Prainsack (2022) Responsible Personalised Medicine: Exploring the Ethical, Legal, Social, Political and Economic Issues of Manu-

facturing, Distribution, Access and Reimbursement. A Report by the Future Targeted Healthcare Manufacturing Hub.

112. Anifandis G, Sutovsky P, Turek PJ, Chavez SL, Kunej T, et al. (2022) Bioethics in human embryology: the double-edged sword of embryo research. Syst Biol Reprod Med 68: 169-179.

113. Godwin S, Elkind S, Carey T, DiGiandomenico K, Balbo A, et al. (2023) Environmental Health and Safety Offers a Biosafety Risk Assessment for a Theoretical Model of a Gene Therapy Process Transfer from Research and Development to Large-Scale Manufacturing. Appl Biosaf 28: 164-175.

114. AL-Eitan L, Alnemri M (2022) Biosafety and Biosecurity in the Era of Biotechnology: The Middle East Region. Journal of Biosafety and Biosecurity.

115. Kuchenmüller T, Boeira L, Oliver S, Moat K, El-Jardali F, et al. (2022) Domains and processes for institutionalizing evidence-informed health policy-making: a critical interpretive synthesis. Health Res Policy Syst 20: 27.

116. Safdar M, Ullah M, Bibi A, Khan MA, Rehman M, et al. (2023) The Evolving Landscape of Biosafety and Biosecurity: A Review of International Guidelines and Best Practices. Journal of Women Medical & Dental College 2: 28-40.

117. Vasodavan K, Theva Das K (2023) Advancing precision medicine with gene and cell therapy in Malaysia: Ethical, Legal, and Social Implications (ELSI). Hum Gene Ther.

118. Lestari F, Kadir A, Miswary T, Maharani CF, Bowolaksono A, et al. (2021) Implementation of Bio-Risk Management System in a National Clinical and Medical Referral Centre Laboratories. Int J Environ Res Public Health 18: 2308.

119. Arzahana IS, Ismaila Z, Yasin SM (2022) Safety culture, safety climate, and safety performance in healthcare facilities: A systematic review. Saf Sci.

120. Yang J, Xuan S, Hu Y, Liu X, Bian M (2022) The framework of safety management on university laboratory. J Loss Prev Process Ind 80.

121. Ahamad MA, Arifin K, Abas A, Mahfudz M, Cyio MB, et al. (2022) Systematic Literature Review on Variables Impacting Organization's Zero Accident Vision in Occupational Safety and Health Perspectives. Sustainability 14: 7523.

122. Yang J, Xuan S, Hu Y, Liu X, Bian M, et al. (2022) The framework of safety management on university laboratory. J Loss Prev Process Ind 80.

123. Back JB, Martinez L, Nettenstrom L, Sheerar D, Thornton S, et al. (2022) Establishing a biosafety plan for a flow cytometry shared resource laboratory. Cytometry A 101: 380-386.

124. Subasinghe R, Alday-Sanz V, Bondad-Reantaso MG, Jie H, Shinn AP, et al. (2023) Biosecurity: Reducing the burden of disease. J World Aquac Soc 54: 397-426.

125. Charitos IA, Ballini A, Cantore S, Boccellino M, Di Domenico M, et al. (2021) Stem Cells: A Historical Review about Biological, Religious, and Ethical Issues. Stem Cells Int 2021: 9978837.

126. Kjeldaas S, Dassler T, Antonsen T, WikmarK OG, Myhr AI, et al. (2023) With great power comes great responsibility: why 'safe enough' is not good enough in debates on new gene technologies. Agric Human Values 40: 533-545.

127. Horn R, Merchant J, Bale M, Chneiweiss H, Hallowell N, et al. (2023) Managing expectations, rights, and duties in large-scale genomics initiatives: a European comparison. Eur J Hum Genet 31: 142-147.

128. Wan Z, Hazel JW, Clayton EW, Vorobeychik Y, Kantarcioglu M, et al. (2022) Sociotechnical safeguards for genomic data privacy. Nat Rev Genet 23: 429-445.

129. Gefenas E, Lekstutiene J, Lukaseviciene V, Hartlev M, Mourby M, et al. (2022) Controversies between regulations of research ethics and protection of personal data: informed consent at a cross-road. Med Health Care Philos 25: 23-30.

130. Burns L, Roux NL, Kalesnik-Orszulak R, Christian J, Hukkelhoven M, et al. (2022) Real-World Evidence for Regulatory Decision-Making: Guidance from Around the World. Clin Ther 44: 420-437.

131. Asokan GV, Mohammed YM (2021) Harnessing the Power of Big Data to Drive Evidence-Based Policy Making in the Public Sector. Big Data in Psychiatry & Neurology, pp. 325-337.

132. Caballe A, Bardelli M (2021) Building Blocks of Virtuous Science Communication: Grant Funding, Policy Making, and Public Engagement. DNA Cell Biol 41: 6-10.

133. Assen LS, Jongsma KR, Isasi R, Tryfonidou MA, Bredenoord AL, et al. (2021) Recognizing the ethical implications of stem cell research: A call for broadening the scope. Stem Cell Reports 16: 1656-1661.

134. Hoang DM, Pham PT, Bach TQ, Ngo AT, Nguyen QT, et al. (2022) Stem cell-based therapy for human diseases. Signal Transduct Target Ther 7: 272.

135. Cao J, Stacey G, Shyh-Chang N, Zhao T (2022) Developing standards to support cell technology applications. Cell Prolif 55: e13210.

136. Proietto M, Crippa M, Damiani C, Pasquale V, Sacco E, et al. (2023) Tumor heterogeneity: preclinical models, emerging technologies, and future applications. Front Oncol 13: 1164535.

137. Gu Y, Zhang W, Wu X, Zhang Y, Xu K, et al. (2023) Organoid assessment technologies. Clin Transl Med 13: e1499.

138. Silva-Pedrosa R, Salgado AJ, Ferreira PE (2023) Revolutionizing Disease Modeling: The Emergence of Organoids in Cellular Systems. Cells 12: 930.

139. Giannelos K, Reber B, Doorn N (2022) Responsive ethics and participation: Science, technology and democracy. Wiley.

140. Lee LM (2023) Research integrity and the regulatory-industrial complex. Account Res, p. 1-11.

141. Ashiwaju, Ibrahim B, Orikpete, Felix O, Uzougbo, et al. (2023) The intersection of artificial intelligence and big data in drug discovery: A review of current trends and future implications. Matrix sci pharma 7: 36-42.

142. Cordeiro JV (2021) Digital Technologies and Data Science as Health Enablers: An Outline of Appealing Promises and Compelling Ethical, Legal, and Social Challenges. Front Med (Lausanne) 8: 647897.

143. Bustin SA, Jellinger KA (2023) Advances in Molecular Medicine: Unravelling Disease Complexity and Pioneering Precision Healthcare. Int J Mol Sci 24: 14168.

144. Restrepo JC, Dueñas D, Corredor Z, Liscano Y (2023) Advances in Genomic Data and Biomarkers: Revolutionizing NSCLC Diagnosis and Treatment. Cancers (Basel) 15: 3474.

145. Laigle L, Chadli L, Moingeon P (2023) Biomarker-driven development of new therapies for autoimmune diseases: current status and future promises. Expert Rev Clin Immunol 19: 305-314.

146. Luengo O, Galvan-Blasco P, Cardona V (2022) Molecular diagnosis contribution for personalized medicine. Curr Opin Allergy Clin Immunol 22: 175-180.

147. Goering S, Klein E, Specker Sullivan L, Wexler A, Agüera Y, et al. (2021) Recommendations for Responsible Development and Application of Neurotechnologies. NEUROETHICS-NETH, p. 1-22.

148. Popa EO, Hilten MV, Oosterkamp E, Bogaardt MJ (2021) The use of digital twins in healthcare: socio-ethical benefits and socio-ethical risks. Life Sciences, Society and Policy 17: 6.

149. Anurogo D, NA Hidayat (2023) The Art of Televasculobiomedicine 5.0. Nas Media Pustaka.

150. Sun T, Xe H, Song X, Shu L, Li Z (2022) The Digital Twin in Medicine: A Key to the Future of Healthcare?. Front Med 9: 907066.

151. Beheshtizadeh N, Gharibshahian M, Pazhouhnia Z, Rostami M, Zangi AR (2022) Commercialization and regulation of regenerative medicine products: Promises, advances and challenges. Biomed Pharmacother 153: 113431.

152. Oliva A, Grassi S, Vetrugno G, Rossi R, Della Morte G, et al. (2022) Management of Medico-Legal Risks in Digital Health Era: A Scoping Review. Front Med (Lausanne) 8: 821756.

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