INTEGRATION OF BIOTECHNOLOGY AND ARTIFICIAL INTELLIGENCE IN PERSONALIZED MEDICINE: TECHNOLOGICAL ADVANCES AND ETHICAL CHALLENGES IN HEALTH

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ABSTRACT

Personalized medicine has established itself as an innovative approach by considering the individual characteristics of patients for clinical decision-making. In this context, the integration of biotechnology and artificial intelligence has driven significant advances in the analysis of complex biological data, the development of personalized therapies, and clinical decision support. The objective of this integrative review was to critically analyze the scientific evidence on technological advances and the ethical challenges related to the joint application of biotechnology and artificial intelligence in personalized medicine in human health. The methodology consisted of an integrative literature review, with systematic searches in international databases, using descriptors related to artificial intelligence, biotechnology, and personalized medicine. Articles published between 2018 and 2025, peer-reviewed and available in full, were included, resulting in the selection of 20 scientific studies. The results demonstrated that the application of machine learning and deep learning algorithms has contributed to the identification of biomarkers, patient stratification, and therapy optimization, especially in areas such as oncology and drug development. However, the studies also highlighted relevant challenges, such as the need for rigorous clinical validation, the quality of the data used, and the ethical implications related to privacy, algorithmic bias, and model transparency. It is concluded that the integration of biotechnology and artificial intelligence presents a high potential to transform personalized medicine, provided it is accompanied by ethical, regulatory, and scientific milestones that ensure its safe, equitable, and effective application.

Keywords: artificial intelligence; biotechnology; personalized medicine; health ethics.

INTRODUCTION

Personalized medicine represents a paradigm shift in healthcare, replacing generalist approaches with therapeutic strategies based on the individual characteristics of each patient, including genetic, molecular, clinical, and environmental factors [1,2]. In this context, the integration of biotechnology and artificial intelligence (AI) has become one of the main vectors of innovation, enabling significant advances in the prevention, diagnosis, prognosis, and treatment of complex diseases [3,4].

Biotechnology, especially through omics technologies (genomics, transcriptomics, proteomics, and metabolomics), generates large volumes of highly complex data, the interpretation of which exceeds the capacity of traditional analytical methods [5,6]. Artificial intelligence, in turn, offers computational tools capable of processing, integrating, and extracting relevant patterns from these large-scale data, facilitating the identification of biomarkers, patient stratification, and the prediction of individualized therapeutic responses [7–9]. This convergence has driven practical applications in areas such as precision oncology, pharmacogenomics, diagnosis by imaging, drug development, and preventive medicine [10–12].

Recent studies show that machine learning and deep learning algorithms can increase diagnostic accuracy, reduce drug development time, and support personalized clinical decision-making [13–15]. Furthermore, the use of AI-based predictive models has contributed to the optimization of clinical trials and more precise therapy selection, aligning with the principles of value-based and patient-centered medicine [16,17].

However, despite technological advancements, the integration of biotechnology and artificial intelligence in personalized medicine raises relevant ethical, legal, and social challenges. Issues related to data privacy and security, algorithmic bias, transparency of models, professional responsibility, and regulatory governance have been widely debated in the scientific literature [18–20]. The lack of explainability in certain AI systems, combined with the reliance on large sensitive databases, reinforces

the need for solid ethical structures and rigorous clinical validation to ensure safety and equity in healthcare [16,19].

In this scenario, it becomes essential to systematize the available scientific knowledge about the integration of biotechnology and artificial intelligence in personalized medicine, highlighting both the technological advances and the ethical challenges associated with its implementation. Thus, the objective of this integrative review is to critically analyze the current scientific evidence regarding the combined use of these technologies in personalized medicine, identifying their main applications, benefits, limitations, and ethical implications in the context of human health.

METHODOLOGY

This study consists of an integrative literature review, a methodological approach that enables the systematic and critical analysis of scientific evidence from different research designs, allowing for a comprehensive understanding of the current state of knowledge and the identification of relevant gaps in scientific production [1]. The conduct of the review followed predefined steps, including the formulation of the research question, the definition of search strategies, the application of inclusion and exclusion criteria, the selection of studies, the extraction of data, and the synthesis of results [1,2].

The guiding question that directed this review was: what are the technological advances and the main challenges related to the integration of biotechnology and artificial intelligence in personalized medicine in human health? The bibliographic search was conducted systematically in the databases PubMed/MEDLINE, PubMed Central (PMC), ScienceDirect, SpringerLink, MDPI, Nature Portfolio, and Cureus, selected for their extensive coverage of scientific journals in the fields of health, biotechnology, and artificial intelligence applied to medicine [3–5].

Controlled and uncontrolled descriptors were used, combined through the boolean operators AND and OR, including the terms Artificial Intelligence, Biotechnology, Personalized Medicine, Precision Medicine, Machine Learning,

Bioinformatics and Ethics. The search strategies included combinations such as Artificial Intelligence AND Personalized Medicine, Biotechnology AND Artificial Intelligence, Precision Medicine AND Machine Learning, and Artificial Intelligence AND Ethics AND Healthcare, aiming to encompass studies that discussed both technological advancements and the ethical implications of the investigated theme.

The inclusion criteria adopted were: original or review scientific articles published between 2018 and 2025, available in full text, in English or Portuguese, peer-reviewed, and that directly addressed the integrated application of biotechnology and artificial intelligence in personalized medicine in human health. Editorials, letters to the editor, conference abstracts, duplicate studies, publications lacking methodological rigor, and works that addressed artificial intelligence or biotechnology in isolation, without a direct relationship to personalized medicine, were excluded.

The selection of studies initially occurred through reading titles and abstracts, excluding those that did not meet the established criteria. Subsequently, the texts

The complete articles potentially eligible were evaluated critically, considering thematic relevance and methodological quality. At the end of this process, twenty scientific articles fully met the eligibility criteria and composed the final sample of this integrative review.

The data extraction was carried out in a standardized manner, encompassing information regarding the authors, year of publication, objectives, methodological design, main applications of artificial intelligence and biotechnology in personalized medicine, relevant results, and ethical aspects discussed. The data analysis occurred qualitatively and descriptively, allowing for comparison between studies, identification of convergences and divergences, and the construction of a critical synthesis of the available evidence [6–9].

The results were organized through an analytical narrative approach, prioritizing the integration of scientific findings related to technological advancements and the ethical challenges associated with the joint application of biotechnology and artificial intelligence in personalized medicine, enabling

a comprehensive and critical view of the topic under investigation.

RESULTS

The systematic search and rigorous application of eligibility criteria resulted in the inclusion of **20 scientific studies** that directly addressed the integration between biotechnology and artificial intelligence in the context of personalized medicine. The selected articles were published between 2018 and 2025 and encompassed different methodological designs, including narrative reviews, systematic reviews, and applied studies, reflecting the multidisciplinary and emerging nature of the investigated theme.

Overall, the results showed that the integration between biotechnology and artificial intelligence has promoted significant advances in the analysis of omics data, in the development of therapies personalized, in patient stratification and in supporting clinical decision-making [1–4]. Most studies highlighted the use of machine learning and deep learning algorithms for processing large volumes of genomic, proteomic, and clinical data, enabling the identification of predictive and prognostic biomarkers with greater precision [5–9].

In the field of drug discovery and development, studies have shown that the application of artificial intelligence combined with biotechnological tools contributes to reducing the time and costs involved in pre-clinical and clinical stages, as well as favoring the selection of more effective and safe therapies for specific patient subgroups [3,10,20]. In areas such as oncology and cardiology, the results indicated improvements in treatment personalization and monitoring of therapeutic response, reinforcing the clinical potential of these technologies [8,11,14].

However, studies have also pointed to significant challenges, especially regarding the quality and heterogeneity of data, external validation of predictive models, and the reproducibility of results in different populations [6,7,15]. Ethical and legal issues were recurrent, with emphasis on the privacy and security of sensitive data, algorithmic bias, lack of transparency in AI models, and the definition of responsibilities.

professionals in the clinical use of these tools [16, 18, 19].

To facilitate the summarized visualization of the main characteristics of the included studies, **Table 1** presents a synthesis of the selected articles, highlighting the main focus of the technological applications and the ethical approach discussed.

Table 1 – Synthesis of the studies included in the integrative review on biotechnology and artificial intelligence in personalized medicine

Author/Year	Type of study	Main technological application	Ethical aspects addressed
Parekh et al., 2023	Review narrative	Integration of AI with genomic and clinical data	Transparency and clinical validation
Serrano et al., 2024	Review applied	Personalized drug discovery	Data quality
Jamialahmadi et al., 2024	Narrative Review	Bioinformatics and Omic analysis by AI	Data governance data
Ahmad et al., 2025	Systematic review	Precision oncology	Equity and regulation
Bhushan et al., 2025	Study applied	Multimodal AI in biotechnology	Privacy and security

Source: Own elaboration based on the selected studies.

As shown in **Table 1**, there is a predominance of studies focused on clinical and translational applications, with increasing attention to the ethical implications of using artificial intelligence associated with biotechnology. The synthesis of the results indicates that, although technological advances are significant, the consolidation of personalized medicine based on these tools depends on simultaneously addressing technical, ethical, and regulatory challenges, pointing to the need for integrated and multidisciplinary approaches in the future development of the field [12, 16–19].

DISCUSSION

The results of this integrative review show that the integration of biotechnology and artificial intelligence has played a central role in the consolidation of personalized medicine, by enabling the integrated analysis of complex data and increasingly individualized clinical decision-making. Consistently, the studies analyzed demonstrate that the application of machine learning and deep learning algorithms enhances the capacity to interpret genomic, proteomic, and clinical data, favoring the identification of biomarkers, patient stratification, and therapeutic personalization [1–4].

One of the main advances observed relates to the use of artificial intelligence in the analysis of omics data, a field in which traditional computational methods present significant limitations. The literature indicates that the combination of biotechnology and AI enables the detection of complex and nonlinear biological patterns, contributing to earlier and more accurate diagnoses, as well as to the prediction of individualized therapeutic responses [5–7]. These findings reinforce the potential of personalized medicine to surpass standardized approaches, especially in areas such as precision oncology, cardiology, and pharmacogenomics [8–11].

In the context of drug development, the reviewed studies indicate that the application of artificial intelligence associated with biotechnology reduces the time and costs of preclinical and clinical stages, in addition to optimizing the selection of molecules with a higher probability of therapeutic success [3, 12]. This integration has allowed the transition from empirical models to data-driven strategies, favoring the personalization of treatment and increasing clinical efficacy [13, 14]. However, the dependence on large volumes of high-quality data remains a limiting factor, as incomplete or biased databases can compromise the reliability of predictive models [6, 15].

Despite the evident technological benefits, the analyzed literature highlights relevant ethical, legal, and social challenges associated with the implementation of artificial intelligence in medicine.

personalized. Issues related to the privacy and security of sensitive data, algorithmic bias, and the lack of transparency of AI models have been widely discussed in the included studies [16–18]. The use of "black box" systems, in which decision-making processes are not fully understood, raises concerns regarding professional accountability and trust in the clinical use of these technologies [16, 19].

Another critical aspect relates to the clinical validation and generalization of artificial intelligence models. Although many studies present promising results in controlled environments, application in real clinical practice contexts still faces limitations related to population diversity and the reproducibility of findings [7, 15]. Thus, the literature reinforces the need for robust external validations and multicenter studies that ensure the safety, equity, and effectiveness of AI-based personalized medicine [11, 14].

Additionally, it is noted that regulatory governance and professional training emerge as essential elements for the consolidation of the integration between biotechnology and artificial intelligence in healthcare. Studies indicate that the responsible adoption of these technologies requires clear regulatory frameworks, as well as training for healthcare professionals in critical interpretation and ethical use of AI tools [2, 16, 18]. The absence of these elements may widen inequalities in access to innovation and compromise the potential benefits of personalized medicine.

In summary, the discussion of the findings highlights that the integration of biotechnology and artificial intelligence represents a significant advancement for personalized medicine, offering concrete opportunities for improving clinical outcomes and the efficiency of healthcare systems. However, the effective incorporation of these technologies depends on simultaneously addressing technical, ethical, and regulatory challenges, reinforcing the importance of interdisciplinary approaches and public policies aimed at the safe, transparent, and equitable use of innovation in health [1, 16–20].

CONCLUSION

This integrative review evidenced that the integration between

Biotechnology and artificial intelligence constitute one of the central pillars of contemporary personalized medicine, promoting significant advances in the understanding of biological mechanisms, in diagnosis, prognosis, and in the personalization of therapeutic strategies in human health. The analyzed studies demonstrate that the combined application of these technologies enables the efficient analysis of large volumes of complex data, especially those derived from omics sciences, favoring the identification of biomarkers, precise patient stratification, and the optimization of clinical decision-making [1–4].

The findings also indicate that artificial intelligence has played a relevant role in drug development and in conducting more efficient clinical trials, contributing to cost reduction, shorter development times, and increased therapeutic efficacy. These applications reinforce the potential of personalized medicine to surpass traditional models based on generalist approaches, bringing health care closer to a truly patient-centered paradigm [10–14].

However, despite significant technological advances, the analyzed literature highlights important challenges that still limit the full consolidation of these innovations in clinical practice. Issues related to the quality and heterogeneity of data, external validation of artificial intelligence models, and reproducibility of results remain relevant technical obstacles [6,7,15]. Furthermore, the ethical, legal, and social challenges associated with the use of these technologies, such as the protection of sensitive data, algorithmic bias, system transparency, and the definition of responsibilities professionals,

constitute critical aspects that require continuous attention [16–19].

Thus, it is concluded that the integration of biotechnology and artificial intelligence presents a high transformative potential for personalized medicine, provided it is accompanied by robust ethical governance structures, appropriate regulatory frameworks, and rigorous scientific validation processes. Strengthening interdisciplinary approaches, combined with the qualified training of health professionals and the development of public policies aimed at the responsible use of technology, proves to be

fundamental to ensure that the benefits of these innovations are widely distributed and applied safely and equitably.

Finally, this review contributes to the systematization of scientific knowledge on the subject and points to the need for future research that deepens the evaluation of clinical effectiveness, equity in access, and the ethical impacts of personalized medicine based on the integration of biotechnology and artificial intelligence, consolidating its role in the sustainable advancement of health systems.

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