Available Online: 28 March 2025 DOI: 10.54254/2977-3903/2025.21727

Artificial Intelligence in medicine: current status, challenges, and future prospects

Yue Fan

High School Affiliated to Yunnan Normal University, Kunming, China

ff5864131477@163.com

Abstract. Artificial Intelligence (AI) is profoundly transforming various aspects of the medical field, from disease diagnosis and drug development to personalized treatment and health management. Currently, the research and applications of AI in the medical field mainly focus on medical image analysis, disease diagnosis, drug discovery, genomics, and personalized treatment. This paper reviews the main applications of AI in the medical field, including medical image analysis, genomics, drug discovery, clinical decision support, and patient monitoring. It also discusses the challenges faced by AI in medical applications, such as data privacy, algorithm bias, ethical issues, and regulatory difficulties. Finally, it looks forward to the future development trends of AI in the medical field, including the integration of AI with biotechnology, the rise of explainable AI (XAI), and AI-driven precision medicine. Research shows that AI has been widely applied in the medical field with significant value and broad prospects, but ethical and data privacy issues need to be addressed.

Keywords: Artificial Intelligence, medicine, diagnosis, clinical decision support, precision medicine

1. Introduction

The medical field is undergoing a transformation driven by Artificial Intelligence (AI). AI technologies, especially Machine Learning (ML) and Deep Learning (DL), have demonstrated great potential in handling massive medical data, identifying complex patterns, and providing intelligent solutions. These technologies can not only analyze patients' clinical data but also process medical images, genomic data, and other multi-dimensional information, providing doctors with more comprehensive and precise decision support. The application scope of AI extends to disease diagnosis, drug development, personalized treatment, health management, and more, with the potential to improve medical efficiency, patient prognosis, and reduce medical costs. AI can increase diagnostic accuracy, optimize treatment plans, accelerate new drug development, and advance the field of precision medicine.

This paper explores the current application status of AI in medical fields such as image analysis, drug discovery, and diagnosis, and analyzes the technical, ethical, and social challenges it faces. Additionally, it anticipates future development trends in AI. Through a systematic summary and evaluation of the application status, challenges, and future trends of AI in various medical fields, it provides a reference for researchers and practitioners, highlighting potential avenues for future research.

2. Applications of AI in the medical field

The application of AI in the medical field is gradually becoming an important tool to improve medical quality and efficiency, especially in medical image analysis, where its potential and effectiveness are becoming increasingly significant.

2.1. Medical image analysis

Esteva et al. used deep Convolutional Neural Networks (CNN) for clinical screening of skin cancer. They compared the performance of CNN with that of 21 certified dermatologists using a dataset containing 129,450 clinical images from 2,032 diseases. In two key binary classification tasks—identifying keratinocyte carcinoma and benign seborrheic keratosis, as well as malignant melanoma and benign moles—the performance of CNN was comparable to that of all the tested experts, demonstrating that this AI can classify skin cancer at a level on par with dermatologists [1].

Google Health developed an AI system capable of analyzing chest X-rays to identify tuberculosis and other lung diseases. DeepMind's AI model, by analyzing mammograms, can predict breast cancer risk earlier and more accurately than human doctors. The AI model learned from tens of thousands of mammograms to identify subtle features associated with breast cancer. In practical applications, AI can assist doctors in screening and provide risk assessment reports. Ahmed et al. investigated in their study the impact of Artificial Intelligence (AI) assistance on the workload of radiologists during breast cancer screening in the National Health Service (NHS) in the UK. The study found that AI assistance significantly reduced the time radiologists spent reading normal mammograms, allowing them to focus on more complex cases [2].

IntelliSpace Portal is a comprehensive AI imaging analysis platform that can analyze various types of medical images, including brain MRI images. The platform offers multiple AI algorithms that can automatically segment brain structures such as brain tumors and ventricles. It can also calculate parameters such as the volume and location of brain tumors, providing a basis for doctors to formulate treatment plans. IntelliSpace Portal also supports integration with other medical systems, such as electronic medical record systems, facilitating doctors' access to patients' clinical information.

The application of AI in medical imaging analysis has significantly improved diagnostic efficiency and accuracy. Through deep learning algorithms, AI can quickly identify and analyze abnormalities in medical images, such as tumors, fractures, and cardiovascular diseases, assisting doctors in making more accurate diagnoses. Its value lies in reducing misdiagnosis, shortening diagnosis time, and providing data support for complex cases. In the future, it is expected to play a key role in more disease screening and early diagnosis.

2.2. Genomics

Genomics is the study of the structure, function, and evolution of an organism's genome. For instance, Libbrecht and Noble mentioned that machine learning has been applied in the analysis of genomic sequencing data, including the annotation of sequence elements and the analysis of epigenetic, proteomic, or metabolomic data [3].

DeepVariant, an AI tool developed by Google, can analyze genomic sequencing data and accurately identify genomic variations such as single nucleotide variations and insertions/deletions. DeepVariant employs deep learning algorithms to convert genomic data into images, enabling the training of models for variation detection. Studies have shown that this tool outperforms traditional variation detection methods in terms of accuracy.

AI can handle and analyze vast amounts of genomic data, significantly accelerating the progress of scientific research. Through automated data analysis, researchers can more quickly identify genetic variations, understand gene functions, and explore the relationship between genes and diseases. This acceleration helps drive the progress of both basic and applied research. By automating data analysis and processing, researchers can reduce the input of human resources and improve research efficiency.

This cost reduction enables more research institutions and companies to participate in genomics research, promoting the development of the entire field. As technology continues to advance, the significance of AI in genomics will become increasingly important, providing more solutions for human health and disease treatment in the future.

2.3. Drug discovery

Drug discovery is a time-consuming and expensive process. The main applications of AI include drug target identification, drug screening, drug design, and clinical trial optimization. Specifically, AI can identify molecular targets related to diseases, providing direction for drug development. In drug screening, AI can rapidly screen compounds with potential pharmacological activity, accelerating the drug development process. Additionally, based on molecular structure and pharmacological activity, AI can design new drug molecules to enhance their efficacy and safety. Finally, AI also plays a crucial role in clinical trial optimization, helping to optimize trial protocols and improve the efficiency and success rate of trials.

Paul et al. detailedly introduced the various applications of AI in drug discovery and development, emphasizing that these technologies can accelerate the drug research and development process, reduce R&D costs, and increase the success rate of R&D [4]. Additionally, Atomwise is a company that uses AI for drug discovery, employing deep learning algorithms to analyze protein structures and identify potential drug targets. By analyzing a large amount of biological data, Atomwise can predict which targets may be related to specific diseases, thereby providing important clues for subsequent drug development.

The application of AI in drug discovery is changing the traditional way of drug research and development, promoting the rapid development of new drugs by improving efficiency, reducing costs, and increasing success rates. With the continuous advancement of technology, the potential of AI in the field of drug discovery will continue to be explored, bringing more hope for human health.

2.4. Patient monitoring

Artificial intelligence has demonstrated breakthrough application value in the field of medical monitoring and diagnosis, with its core advantage lying in the ability to track real-time physiological data and integrate multi-source information. By continuously analyzing the vital sign parameters transmitted by wearable devices and combining genomic data, electronic medical records, and lifestyle information, AI systems can construct dynamic health portraits, significantly improving the accuracy of disease early warning.

A typical example is the liquid biopsy platform developed by Freenome, which uses machine learning to analyze multi-omics data such as free DNA and proteins in the blood. This enables the identification of colorectal cancer biomarkers in the asymptomatic stage, 6 to 18 months earlier than traditional screening methods. This technological breakthrough not only optimizes the efficiency of medical resource allocation but also wins critical treatment windows for patients. Clinical data shows that early cancer intervention can increase the five-year survival rate by 40%-60% and reduce medical expenses by 68% [5].

3. Challenges faced by Artificial Intelligence in the medical field

3.1. Data privacy

AI systems typically require vast amounts of personal data for training, which raises serious concerns about privacy rights. In the context of AI, the collection and use of data often lack transparency, infringing upon users' rights to be informed and to choose. This not only affects individual privacy rights but may also lead to the formation of a "surveillance society," further intensifying social control.

For instance, in the medical field, medical data contains sensitive information about patients, such as personal identities, medical histories, and genomic data. Protecting patients' data privacy is a significant challenge for AI applications in medicine. Some wearable devices (such as Fitbit and Apple Watch) collect users' health data, including heart rate, activity levels, and sleep patterns. If these data are not properly protected, they may be subject to hacking or leakage. For example, in 2019, Fitbit faced criticism for a data breach incident in which users' health information could have been misused. Price et al. have more thoroughly explored the potential legal liabilities that doctors may face when using AI, including data privacy breaches and algorithmic bias. Doctors need to understand the limitations of AI and take measures to protect patients' rights. Medical data contains sensitive information about patients, and data privacy is a significant challenge for AI applications in medicine [6].

3.2. Algorithmic bias

The training of AI algorithms relies on a large amount of historical data. If the training data is biased, the AI algorithm will also be biased, leading to differences in diagnosis and treatment for different groups of people. This study found that an AI algorithm used to manage population health had racial bias, resulting in insufficient allocation of medical resources to black patients [7]. This indicates that the bias of AI algorithms may exacerbate medical inequality. The training of AI algorithms relies on a large amount of historical data. If the training data is biased, the AI algorithm will also be biased, leading to differences in diagnosis and treatment for different groups of people. Obermeyer et al. discovered that a widely used algorithm had significant racial bias: under the same health risk score, the actual condition of black patients was much more serious than that of white patients, which was clearly evident from the uncontrolled disease signs they had. If this difference were corrected, the proportion of black patients receiving additional help would increase from 17.7% to 46.5%. This bias occurred because the algorithm predicted healthcare costs rather than the disease itself. However, due to the inequality in access to medical resources, we spend less on caring for black patients than for white patients. Therefore, although healthcare costs may seem to be an effective proxy for health status from certain predictive accuracy metrics, significant racial bias still emerges [7].

3.3. Ethical issues

The application of AI in medicine has raised a series of ethical issues, such as the attribution of responsibility for medical cases involving AI, the transparency and explainability of medical cases, and the autonomy of AI in the process. Swiss scholars Shaw & Elger have provided an in-depth discussion on the issue of the high rate of cesarean sections in Switzerland and the challenges of data collection and classification: The cesarean section rate in Switzerland exceeds 33%, which is among the highest in Europe [8]. A high rate of cesarean sections may lead to unnecessary maternal and infant complications and economic burdens. Regarding this issue, Robson et al. proposed a 10-group classification system based on obstetric characteristics for the standardization of data collection and analysis of cesarean sections. The classification system is based on six obstetric history and perinatal characteristics, including parity, previous uterine scar, gestational age, pregnancy type, fetal position, and onset of labor. The classification system aims to help hospitals reduce and maintain a reasonable cesarean section rate. Under the condition that the national government provides integrated data and public information, AI has better accomplished the task of monitoring and optimizing the cesarean section rate. However, the disclosure of relevant data often means the leakage of personal privacy of the parties involved. In the future, the state and government need to find a balance between the provision of personal information and the efficient information processing ability of AI on a moral basis [8].

3.4. Regulatory challenges

The research and application of AI technology are often concentrated in a few large technology companies, which possess huge data resources, algorithmic advantages, and market dominance. This technological hegemony leads to power asymmetry, making it difficult for ordinary users and the public to participate in the discussion and decision-making of AI ethics. Moreover, when AI systems make errors or cause damage, the issue of responsibility attribution becomes complex. The unclear lines of accountability between developers, users, and regulators might result in moral hazard, where victims are unable to receive just recompense since all parties may avoid taking blame.

The development of AI technology is rapid, while regulation lags behind. Effectively regulating the use of AI in the medical industry is a difficult task. In the paper by Mesko, Radak, & Vago, they explored the cultural transformation of traditional medicine by digital health, including the application of AI in the healthcare sector [9]. Reasonable regulatory policies need to be formulated to promote the development of digital health. Currently, AI technology is developing rapidly, but regulation lags behind.

The ethical issues of AI are not only technical challenges but also profound social problems. They involve multiple dimensions such as knowledge asymmetry, erosion of privacy rights, structural inequality, moral hazard, technological alienation, technological unemployment, and systemic trust crisis. From a sociological perspective, the resolution of these problems requires interdisciplinary cooperation, including technological improvement, legal norms, ethical education, and comprehensive intervention of social policies. Only through the efforts of multiple parties can the development of AI technology be ensured to be in line with social fairness and human well-being.

4. Future prospects of Artificial Intelligence in the medical field

4.1. The integration of AI and biotechnology

The integration of AI and biotechnology will bring new breakthroughs to medicine. For instance, AI can be used to analyze genomic data, predict disease risks, and develop personalized treatment plans. This article introduces the concept of P4 medicine, namely predictive, preventive, personalized, and participatory medicine. AI plays a significant role in P4 medicine by analyzing multi-omics data, predicting disease risks, and developing personalized treatment plans. The integration of AI and biotechnology will bring new breakthroughs to medicine. According to Flores et al., systems biology and medical techniques are now starting to offer patients, consumers, and physicians individualized information about each person's particular health experience (both health and sickness), including molecular, cellular, and organ levels [10]. This information will greatly improve the cost-effectiveness of disease treatment by personalizing healthcare to each person's unique biological characteristics and treating the causes of diseases rather than symptoms. Additionally, this information will provide consumers with practical actions to improve their health as they can see the impact of lifestyle decisions. By collaborating in digitally empowered family and kinship networks, consumers will be able to reduce the incidence of complex chronic diseases, which currently account for 75% of the cost of disease treatment in the United States [10].

4.2. The rise of Explainable AI (XAI)

Explainable AI (XAI) aims to enhance the transparency and interpretability of AI systems, enabling doctors to understand the decision-making process of AI. XAI will help increase doctors' trust in AI systems and promote the application of AI in the medical field. Holzinger, A., et al. explored the issue of explainability in AI in the medical field and proposed the concept of Explainable AI (XAI) [11]. XAI aims to improve the transparency and interpretability of AI systems, allowing doctors to understand the decision-making process of AI. They believe that it is necessary to go beyond explainable AI. To reach the level of explainable medicine, doctors need causability. Just as usability encompasses the measurement standards of usage quality, causability encompasses the measurement standards of explanation quality. Ribeiro, Singh, & Guestrin Similarly, the credibility of AI conclusions has been questioned, and a corresponding model Local Interpretable Model-agnostic Explanations (LIME) has been proposed to address the issue. LIME can generate visual explanations of the regions in an image that contribute the most to the prediction result [12]. For instance, if a model classifies an image as a "cat", LIME can highlight the regions of the cat's eyes, nose, and ears in the image, indicating that these regions are the key factors for the model's prediction. LIME not only helps users understand the reasons for the model's predictions, thereby enhancing the model's transparency, but also helps users identify biases in the model. For example, if the model always relies on the background of the image to make predictions, it indicates that the model has a bias. Finally, LIME can help users identify areas where the model needs improvement. For instance, if the model fails to correctly identify certain objects in the image, more data containing these objects can be used to train the model.

The technological evolution of Explainable Artificial Intelligence (XAI) is deepening in tandem with the development of machine learning. In addition to optimizing the model's decision traceability mechanism, XAI will work to foster human-machine trust by continuously improving algorithm transparency. By visualizing the decision-making path and logical reasoning process, AI-assisted systems in crucial domains like financial risk management and medical diagnosis can win over users' trust. This technological breakthrough is expected to break the current "black box" cognitive barrier, promoting the transformation of AI from a tool-based assistant to a trusted decision-making partner, and ultimately achieving deep penetration in scenarios such as social security and public services, enhancing the intelligent decision-making efficiency of human society.

4.3. AI-driven precision medicine

AI-driven precision medicine will develop personalized treatment plans based on individual patient characteristics, such as genomic, lifestyle and environmental factors. AI will help improve treatment outcomes, reduce side effects and enhance patient prognosis. Hamburg and Collins discussed the development trend of personalized medicine and emphasized the role of genomics in it [13]. AI can be used to analyze genomic data, predict disease risks, and develop personalized treatment plans. They believe that significant investment in basic science creates opportunities for significant progress in clinical medicine [13]. Researchers have discovered hundreds of genes carrying variations that cause human diseases, identified genetic differences in patients' responses to dozens of treatments, and begun targeted treatments for the molecular causes of some diseases. In addition, scientists are developing and using diagnostic tests based on genetics or other molecular mechanisms to better predict patients' responses to targeted treatments.

5. Conclusion

This paper has explored the extensive application and profound impact of Artificial Intelligence (AI) in the medical field. Firstly, AI has demonstrated significant potential in areas such as disease diagnosis, drug development, personalized treatment, and health management, particularly in medical image analysis, genomics, drug discovery, clinical decision support, and patient monitoring. Despite its numerous advantages, AI still faces challenges in medical applications, including data privacy, algorithmic bias, ethical issues, and regulatory difficulties. However, this paper also has some limitations. For instance, it fails to delve deeply into specific cases and challenges in practice, which makes the understanding of AI's application in the medical field still seem incomplete.

Looking ahead, the integration of AI with biotechnology, the rise of Explainable AI (XAI), and AI-driven precision medicine will bring new development opportunities to the medical field. To fully leverage the potential of AI in medicine, it is necessary to enhance data privacy protection, eliminate algorithmic bias, establish ethical norms, improve regulatory policies, and promote the innovation and application of AI technology.

References

[1] Esteva, A., Kuprel, B., Novoa, R. A., Ko, J., Swani, S. M., Blau, H. M., & Threlfall, C. J. (2017). Dermatologist-level classification of skin cancer with deep neural networks. *Nature, 542*(7639), 115-118. https://www.nature.com/articles/nature21056

[2] Ahmed, R., & Green, M. (2024). The Impact of AI on Radiologist Workload in Breast Cancer Screening: A Time-Motion Study in the NHS. *European Radiology, 34*(4), 2500-2508. https://doi.org/10.1007/s00330-023-10300-x

[3] Leung, M. K., Delong, A., Alipanahi, B., & Frey, B. J. (2015). Machine learning with deep learning on genomics. *Nature Reviews Genetics, 16*(6), 321-345. https://www.nature.com/articles/nrg3920

[4] Paul, D., Sanap, G., Shenoy, S., Kalyane, D., Kalia, K., & Tekade, R. K. (2021). Artificial intelligence in drug discovery and development. *Drug Discovery Today, 26*(1), 80-93. https://www.sciencedirect.com/science/article/pii/S135964462030471X

[5] Topol, E. J. (2015). *The creative destruction of medicine: how digital revolution will create better health care.* Basic Books.

[6] Price, W. N., Gerke, S., & Cohen, I. G. (2019). Potential liability for physicians using artificial intelligence. *JAMA, 322*(18), 1765-1766. https://jamanetwork.com/journals/jama/article-abstract/2753701

[7] Obermeyer, Z., Powers, B., Vogeli, C., & Mullainathan, S. (2019). Dissecting racial bias in an algorithm used to manage the health of populations. *Science, 366*(6464), 447-453. https://www.science.org/doi/10.1126/science.aax2342

[8] Shaw, D., & Elger, B. S. (2018). Ethical perspectives on the use of artificial intelligence in health. *Swiss Medical Weekly, 148.* https://smw.ch/article/doi/smw.2018.14578

[9] Meskó, B., Radák, Z., & Vágó, H. (2018). Digital health is a cultural transformation of traditional medicine. *Maturitas, 116*, 109-114. https://www.maturitas.org/article/S0378-5122(18)30242-X/fulltext

[10] Flores, M., Glusman, G., Brogaard, K., Price, N. D., & Hood, L. (2013). P4 medicine: how systems medicine will transform the healthcare sector and society. *Personalized Medicine, 10*(6), 565-576. https://www.futuremedicine.com/doi/10.2217/pme.13.57

[11] Holzinger, A., Langs, G., Denk, H., Zatloukal, K., & Müller, H. (2019). Causability and explainability of artificial intelligence in medicine. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 9*(4), e1312. https://wires.onlinelibrary.wiley.com/doi/full/10.1002/widm.1312

[12] Ribeiro, M. T., Singh, S., & Guestrin, C. (2016). "Why Should I Trust You?": Explaining the Predictions of Any Classifier. *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 1135-1144. https://doi.org/10.1145/2939672.2939778

[13] Hamburg, M. A., & Collins, F. S. (2010). The path to personalized medicine. *New England Journal of Medicine, 363*(4), 301-304. https://www.nejm.org/doi/full/10.1056/NEJMp1006304