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REVIEW ARTICLE

Advancing Personalised and Precision Medicine Through Artificial Intelligence: Current Insights and Future Directions

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Abstract

The convergence of artificial intelligence (AI) and precision medicine is transforming healthcare by introducing a patient-centred, data-driven approach to treatment. Precision medicine, which tailors medical care based on individual characteristics, addresses the complexity and heterogeneity of diseases. The integration of AI into this field has unlocked unprecedented potential for enhancing disease management and advancing personalised care. AI leverages extensive datasets, including genomic sequences, clinical records and molecular profiles, to identify patterns and predict outcomes with remarkable accuracy. Its capabilities extend beyond automation, functioning as a critical tool for informed clinical decision-making. By analysing complex molecular data, AI enhances diagnostic precision through the detection of subtle biomarkers and anomalies frequently overlooked by traditional methods. Machine learning–powered predictive analytics further empower clinicians by forecasting disease progression and guiding treatment personalisation. Practical applications of AI-driven precision medicine are already evident in clinical settings. From diagnosing rare genetic disorders to optimising drug therapies based on genetic profiles, AI is fundamentally reshaping patient care. However, critical challenges, including ethical considerations, data privacy and the need for transparent algorithms, persist. This review examines the synergistic relationship between AI and precision medicine, highlighting ongoing research, technological innovations and interdisciplinary collaboration. Together, these advancements herald a transformative era in healthcare, paving the way for highly personalised and effective therapeutic strategies.

Key words: Artificial intelligence; Precision medicine; Future treatment; Delivery of health care; Deep Learning; Data analytics; Predictive learning models.

Introduction

In recent years, the convergence of artificial intelligence (AI) and precision medicine has initiated a transformative shift in healthcare, promising to revolutionise the diagnosis, treatment and management of diseases. Precision medicine, also known as personalised or stratified medicine, aims to tailor medical interventions to individual patient characteristics, including genetic makeup, environmental exposures and lifestyle choices. AI encompasses a diverse array of computational techniques that enable machines to emulate human intelligence, learn from data and generate predictions or make decisions. The integration of AI and precision medicine represents a paradigm shift in healthcare delivery, offering unprecedented opportunities to improve patient outcomes, refine clinical decision-making and propel biomedical research forward. By leveraging AI-driven analytics, predictive modelling and decision support systems, healthcare providers can extract valuable insights from extensive datasets, including genomic, clinical, imaging and wearable device data.[1]

AI-driven precision medicine holds considerable promise across multiple healthcare domains, including disease diagnosis, risk stratification, treatment selection and patient management. For example, AI algorithms can analyse genomic data to identify genetic variants associated with disease risk, treatment response and drug metabolism, thereby guiding personalised treatment strategies tailored to individual patients.[2] Additionally, AI-driven diagnostic tools such as deep learning algorithms for medical imaging analysis can assist clinicians in detecting diseases at earlier stages with greater accuracy, facilitating timely interventions and improving patient outcomes.[3] Moreover, AI-powered predictive analytics models can forecast disease trajectories, predict treatment responses and identify individuals at risk of developing specific conditions, enabling proactive interventions and preventive strategies that mitigate health risks and improve population health.[4] By leveraging real-time data streams from electronic health records, wearable devices and other sources, AI-driven systems can continuously monitor patient health status, detect early warning signs of disease exacerbation and deliver personalised recommendations for disease management and lifestyle modification.

The transformative potential of AI and precision medicine extends beyond clinical practice to encompass biomedical research, drug discovery, public health and healthcare policy. AI-driven approaches accelerate biomedical research by analysing large-scale datasets, uncovering disease biomarkers and identifying novel therapeutic targets.[5] Additionally, AI technologies facilitate the development of innovative healthcare solutions, including AI-driven drug discovery platforms, remote patient monitoring systems and predictive analytics models for disease surveillance and outbreak forecasting. The integration of AI and precision medicine is paving the way for future therapies by revolutionising healthcare delivery, biomedical research and public health initiatives. By harnessing AI-driven analytics and personalised treatment strategies, healthcare providers can optimise patient care, enhance health outcomes and advance medical practice in the 21st century. Although AI has increasingly become a transformative force in healthcare, its convergence with precision medicine represents a paradigm shift with far-reaching implications for individualised treatment strategies. Previous reviews have typically addressed AI applications in healthcare broadly or precision medicine within isolated clinical domains.[4, 5]

However, this review uniquely integrates the current landscape of AI-driven tools with the evolving framework of precision medicine, offering a comprehensive synthesis spanning genomics, imaging, diagnostics, therapeutics and predictive analytics. It bridges the interdisciplinary gap between computational innovation and clinical applicability, while highlighting emerging trends, ethical considerations and translational challenges. This review aimed to critically examine how AI can be used in diagnosis and treatment, revolutionising precision medicine, identify knowledge gaps and suggest future directions for research and clinical practice. This fresh perspective sets this review apart from earlier work by offering a cohesive, forward-looking roadmap that highlights the transformative potential of AI in shaping the future of patient-specific treatment.

Study design and methods

This review emloyed a narrative synthesis approach to explore and critically analyse the convergence of AI and precision medicine. A comprehensive literature search was conducted to identify relevant peer-reviewed articles, reviews and key reports published in English, encompassing both foundational and recent studies up to 2025. The inclusion of earlier references provides historical context and conceptual grounding, while recent publications offer insights into current advancements and emerging trends in the field.

Literature search strategy

The databases *PubMed, Scopus, Web of Science* and *Google Scholar* were systematically searched using combinations of the following keywords: "artificial intelligence," "machine learning," "deep learning," "precision medicine," "personalised treatment," "genomics," "predictive analytics," "biomarkers," and "clinical decision support." Boolean operators (AND, OR) were applied to refine the search parameters.

- **Inclusion criteria:** Articles discussing the application of AI in precision medicine across domains such as diagnostics, prognostics, therapeutics, drug discovery, genomics, imaging and clinical decision-making.
- **Exclusion criteria:** Studies not directly focused on AI or precision medicine, non-English publications, editorial pieces and duplicate records.

Two independent reviewers screened titles and abstracts to assess relevance. Subsequently, full texts were evaluated against predefined criteria for inclusion. Selected articles were categorised into the following thematic areas to support the narrative framework: 1) AI in diagnostics and early detection; 2) AI-driven genomics and biomarker discovery; 3) personalised therapeutics; 4) challenges in clinical translation; and 5) ethical and regulatory considerations.

Key information was extracted from the selected studies, including study objectives, methodologies, outcomes and AI model types. The data were qualitatively synthesised to highlight current trends, innovations, limitations and future directions in integrating AI with precision medicine.

Artificial intelligence (AI)

AI has emerged as a transformative force in healthcare, revolutionising multiple facets of clinical practice, biomedical research and public health initiatives. It comprises a diverse array of computational techniques that enable machines to emulate human intelligence, learn from data and generate predictions or make decisions. In healthcare, AI holds significant promise across multiple domains, including disease diagnosis, treatment optimisation, patient management and healthcare delivery. AI-driven diagnostic tools, particularly deep learning algorithms applied to medical imaging analysis, have demonstrated remarkable accuracy in detecting diseases from radiological images. For example, a deep learning algorithm classifies skin cancer at a dermatologist level using dermoscopic images, demonstrating AI's potential to improve diagnostic accuracy and efficiency substantially. Moreover, AI-powered predictive analytics

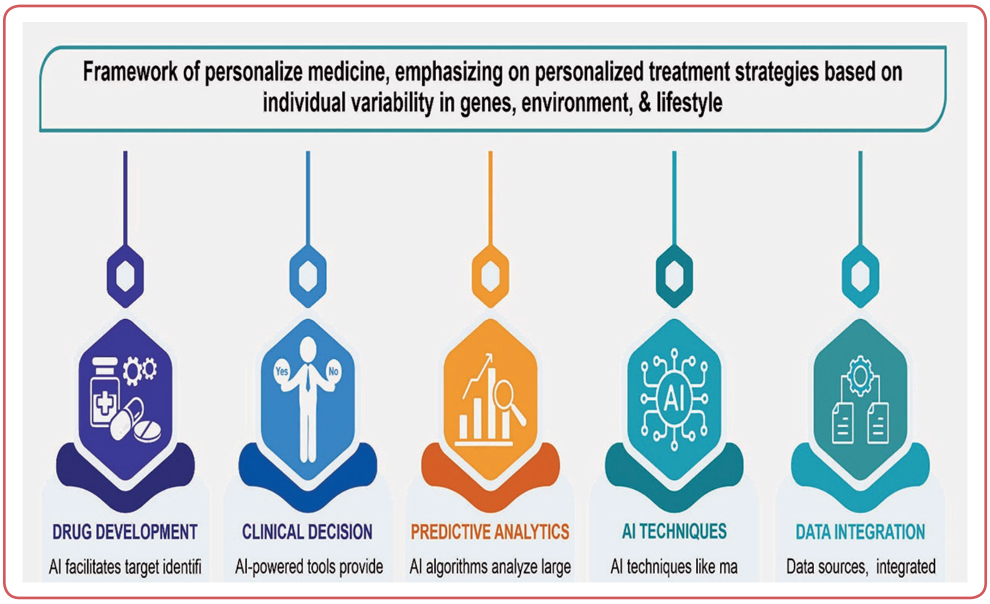

Figure 1: The essential steps involved in developing personalised medicine. This process begins with identifying deregulated molecular targets, which are then addressed through tailored therapies guided by artificial intelligence (AI). Given the critical role of clinical decision-making in determining disease prognosis, AI is employed to stratify patients based on treatment response and to inform the design of individualised treatments plans

models have been employed to forecast disease trajectories, predict treatment responses and identify individuals at risk of developing specific conditions.[6] Other developed and validated a predictive model assessing the short-term risk of worsening renal function in patients with acute decompensated heart failure, highlighting how AI-driven approaches can enhance risk stratification and facilitate more personalised patient care.[7] Beyond its clinical applications, AI is transforming biomedical research by analysing large-scale datasets, uncovering disease biomarkers and identifying novel therapeutic targets.

Deep learning theory is identifying potent inhibitors of DDR1 kinase for the treatment of fibrotic diseases, demonstrating the potential of AI-driven drug discovery platforms to accelerate the drug development process.[8] Furthermore, AI technologies facilitate the development of innovative healthcare solutions, encompassing remote patient monitoring systems, predictive analytics models for disease surveillance and virtual assistants for healthcare providers. These AI-driven solutions hold the potential to improve access to healthcare, enhance patient engagement and optimise resource allocation within healthcare systems. AI represents a transformative force in healthcare, offering unprecedented opportunities to improve patient outcomes, advance biomedical research and enhance healthcare delivery. Figure 1 shows that by leveraging AI-driven analytics and personalised treatment strategies, healthcare providers can optimise patient care, improve health outcomes and shape the future of medicine.

Precision medicine

Precision medicine, also known as personalised or stratified medicine, is an innovative healthcare approach that emphasises tailoring medical interventions to individual patient characteristics, such as genetic makeup, environmental exposures and lifestyle factors. This shift from a one-size-fits-all approach to a more personalised and targeted strategy offers significant potential for improving patient outcomes, enhancing treatment effectiveness and advancing biomedical research. At the heart of precision medicine is the idea of using comprehensive patient data, including genomic, clinical imaging and lifestyle information, to inform medical decision-making and guide treatment strategies. Genomic sequencing technologies, including next-generation sequencing (NGS), enable the identification of genetic variants linked to disease susceptibility, treatment response and drug metabolism. For instance, studies have demonstrated the utility of genomic profiling to guide targeted therapies in cancer patients harbouring specific genetic mutations.[9, 10]

Beyond genomic data, clinical and phenotypic information also play crucial roles in precision medicine. Electronic health records (EHRs) and clinical databases offer valuable insights into patient demographics, medical histories, comorbidities and treatment outcomes. Integrating these data sources with advanced analytics and machine learning algorithms facilitates the development of predictive models for disease risk assessment, prognosis prediction and treatment optimisation.[11, 12] Moreover, precision medicine extends beyond individual patient care to include population health management and public health initiatives. By analysing large-scale datasets and identifying patterns of disease prevalence, risk factors and disparities, precision medicine approaches can inform targeted interventions, preventive strategies and healthcare policies designed to improve population health outcomes.[13-15] Precision medicine represents a transformative healthcare approach that harnesses comprehensive patient data, advanced analytics and personalised treatment strategies to optimise patient care, advance biomedical research and improve population health. By integrating genomic, clinical and lifestyle information, precision medicine enables healthcare providers to deliver more effective, targeted and personalised interventions tailored to the unique needs and characteristics of individual patients (Table 1).

Role of AI in healthcare

AI plays a multifaceted role in healthcare, encompassing diverse applications designed to improve diagnostics, treatment planning and overall patient care. The following section provides an overview of the primary functions of AI in healthcare, as shown in Figure 2.

Table 1: Summary of the role of artificial intelligence (AI) in precision medicine and insights into its potential applications for future treatment strategies

Aspect	Role of AI in precision medicine	Future potential
Data integration	Integrates genomic, proteomic and clinical data to generate comprehensive patient profiles.	Facilitates personalised treatment plans by incorporating multi-omics and real-time patient data.
Disease screening	Detects early disease by identifying patterns in large datasets, including imaging and biomarker data.	Facilitates personalised treatment plans by incorporating multi-omics and real-time patient data.
Precision diagnosis	Employs machine learning to analyse imaging, pathology and molecular data, enabling accurate and personalised diagnoses.	Develops predictive models for disease progression and subtype classification to support tailored interventions.
Treatment decision-making	Supports clinicians by predicting treatment responses and recommending optimal therapies tailored to patient-specific data.	Future AI advancements may enable fully automated, adaptive treatment systems integrated into clinical practice.
Drug development	Accelerates drug discovery by identifying molecular targets and predicting compound efficacy through AI-based simulations.	Transforms pharmaceutical development with faster, cost-effective clinical trials and AI-driven drug design.
Telemedicine	Facilitates remote consultations using AI-driven diagnostic tools and real-time data analytics.	Improves access to personalised healthcare, especially in resource-limited settings.
Prognosis prediction	Utilises AI-based risk models to predict disease outcomes and survival probabilities.	Develops dynamic prognostic tools adaptable to changes in patient health data over time.

Diagnostic assistance

AI has emerged as a powerful tool for diagnostic assistance, especially in pathology and histopathology, where it significantly advances diagnostic accuracy, efficiency and patient outcomes. By leveraging deep learning algorithms and automated image recognition, AI enhances the interpretation of medical images and microscopic tissue samples, thereby enabling healthcare professionals to achieve faster and more accurate diagnoses. In diagnostic imaging, AI algorithms analyse medical images, including X-rays, magnetic resonance imaging (MRI) and computed tomography (CT) scans, to identify patterns and abnormalities, thereby assisting radiologists in interpreting complex imaging data.[6] Similarly, AI algorithms assist pathologists by automating image recognition and pattern detection to analyse microscopic tissue images, enabling the precise identification of anomalies such as cancer cells and other tissue abnormalities.[16]

A significant contribution of AI in pathology is the early detection of cancer, as AI algorithms accurately identify cancerous cells in pathology slides, thereby facilitating timely intervention and treatment planning.[17] Additionally, AI supports tumour grading by providing valuable information to guide treatment decisions and patient management. Furthermore, AI models analyse histopathological data to predict patient outcomes such as survival rates and disease recurrence thereby assisting clinicians in developing personalised treatment plans.[18] By processing pathology slides considerably faster than human counterparts, AI reduces diagnostic turnaround times, which is especially critical in urgent cases requiring prompt intervention. AI also standardises diagnostic practices by minimising inter-observer variability and delivering consistent, objective analyses, thereby enhancing diagnostic accuracy and reliability.[19] Moreover, AI facilitates telepathology by enabling remote analysis of pathology slides, thereby supporting consultations, collaborations and second opinions across geographical distances.[20] Furthermore, AI integrates histopathological data with other patient information, including genomic and clinical data, thereby providing a comprehensive understanding of disease mechanisms and advancing personalised medicine.[21] This integration enables clinicians to tailor treatment plans based on individual patient characteristics, thereby optimising therapeutic efficacy and improving patient outcomes. In pathology and histopathology, AI represents a paradigm shift in diagnostic assistance, offering substantial potential to enhance diagnostic accuracy, efficiency and patient outcomes. As technology advances, collaboration between AI and healthcare professionals is expected to transform pathology further, contributing to more precise and personalised healthcare.

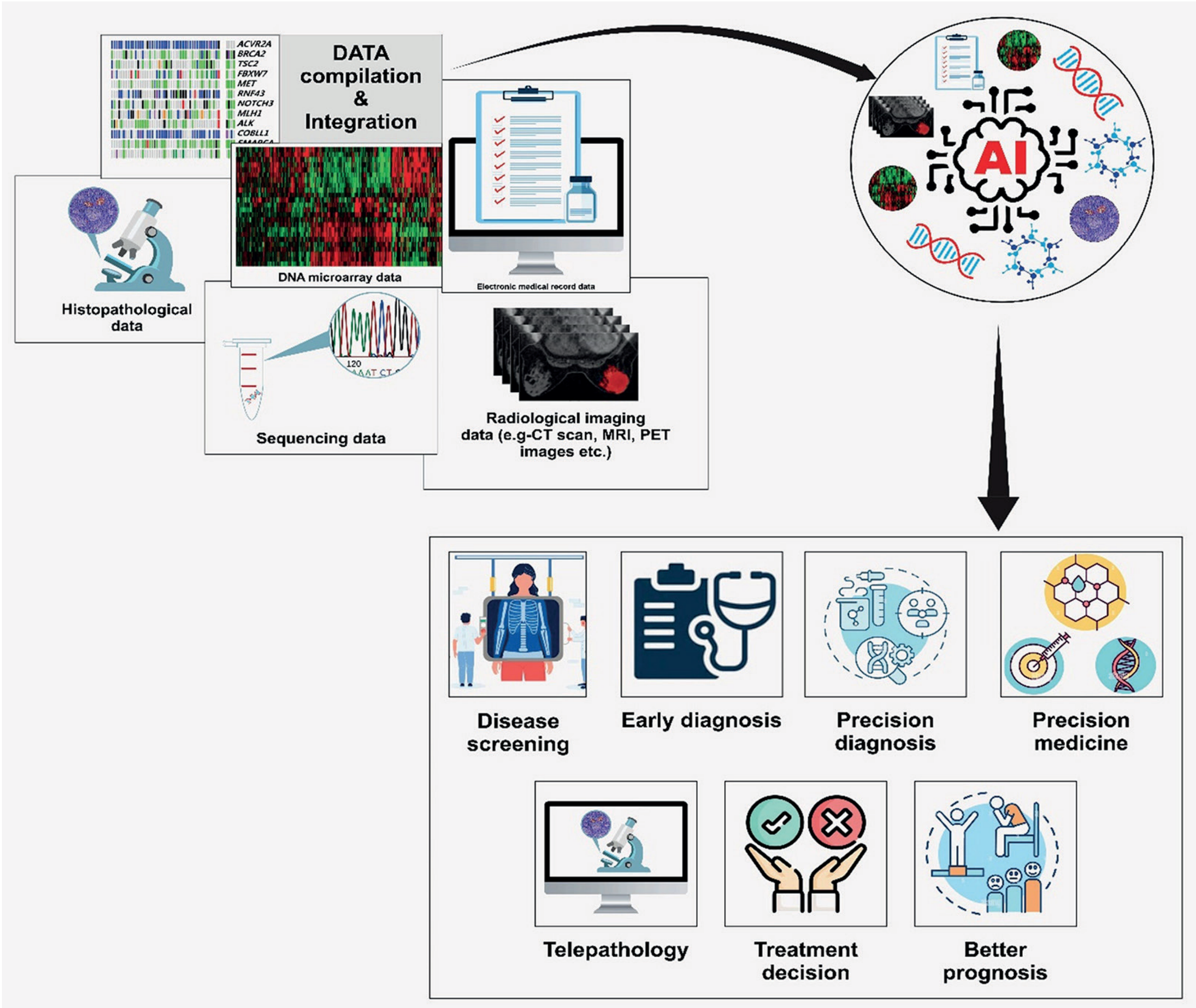

Figure 2: Diagrammatic representation of how artificial intelligence (AI) leverages algorithms such as neural networks, support vector machines and regression techniques in personalised medicine. AI helps to analyse large biological datasets derived from genomics, proteomics and imaging technologies such as CT, MRI and PET techniques. Machine learning and deep learning methodologies develop models for disease screening, precision diagnosis, telepathology, treatment planning and prognosis

Pathology and histopathology

In pathology and histopathology, the integration of AI has ushered in a new era marked by enhanced diagnostic capabilities and streamlined workflows. AI algorithms, especially those used in automated image analysis, have revolutionised the field by enabling rapid and precise interpretation of microscopic images. These systems serve as invaluable aids to pathologists, allowing the identification and characterisation of tissue anomalies with unprecedented accuracy and efficiency.[22] In the context of cancer pathology, AI plays a pivotal role in early tumour detection and grading, providing critical insights that guide treatment decisions and prognoses. By accelerating diagnostic workflows, AI significantly reduces turnaround times, thereby enabling prompt interventions and improving patient outcomes.[23, 24] Moreover, AI promotes standardisation and quality assurance in pathology by mitigating inter-observer variability, thereby providing consistent and objective evaluations across diverse cohorts of pathologists. This is particularly crucial for maintaining diagnostic accuracy and reliability.[25, 26]

The integration of AI extends beyond diagnostic assistance to include predictive analytics for patient outcomes. By leveraging large datasets, AI-powered models assist clinicians in devising personalised treatment strategies tailored to individual patient profiles, thereby optimising therapeutic efficacy and clinical outcomes.[27, 28] Telepathology is another domain enhanced by AI, facilitating remote slide analysis and enabling collaborative consultations among pathologists regardless of geographical barriers. This innovation not only improves diagnostic efficiency but also fosters knowledge exchange and interdisciplinary collaboration.[29] The transformative synergy between AI and pathology not only augments diagnostic accuracy but also opens avenues for comprehensive data integration. By linking histopathological findings with genomic and clinical data, AI facilitates a deeper understanding of disease mechanisms and advances precision medicine paradigms. The integration of AI is poised to revolutionise pathology, ultimately enhancing patient care and outcomes in the coming years.

Cancer detection and grading

AI has ushered in a new era in cancer detection and grading, fundamentally transforming pathology and significantly improving diagnostic accuracy and efficiency. By leveraging advanced algorithms and machine learning techniques, AI revolutionises the analysis of pathology slides, enabling rapid and precise identification of cancerous cells and anomalies with accuracy that often surpasses human capabilities.[22, 25] Early detection is paramount for effective cancer treatment and AI plays a pivotal role by swiftly identifying cancerous cells and abnormalities in pathology slides. AI algorithms' ability to detect subtle morphological changes indicative of malignancy enables pathologists to diagnose cancer at its earliest stages, facilitating timely interventions and improving patient outcomes.[17, 23] Furthermore, AI contributes to tumour grading, a critical component of cancer diagnosis and treatment planning. By objectively evaluating the microscopic features of cancer cells, AI provides standardised and reproducible tumour grade assessments, helping clinicians stratify patients by disease aggressiveness and tailor treatment strategies accordingly.[25, 28]

The integration of AI in cancer pathology holds great promise for reducing subjectivity and variability inherent in traditional diagnostic methods. By providing consistent and objective evaluations, AI algorithms enhance the reliability and validity of tumour grading, thereby improving the accuracy of prognostic assessments and guiding treatment decisions.[16, 29] Moreover, AI accelerates diagnostic timelines by expediting the analysis of pathology slides, significantly reducing turnaround times and enabling prompt initiation of treatment. This rapidity is particularly crucial in cancer diagnosis, where timely intervention can substantially improve patient outcomes and survival rates.[24, 27] The integration of AI in cancer detection and grading represents a paradigm shift in pathology, offering unparalleled opportunities to improve diagnostic accuracy, efficiency and patient outcomes. By harnessing advanced algorithms and machine learning techniques, AI enables early cancer detection, objective tumour grade evaluation and personalised treatment planning, ultimately contributing to the ongoing fight against cancer.

Prediction of patient outcomes

AI has emerged as a transformative force in healthcare, particularly in predicting patient outcomes through advanced analytics and machine learning algorithms. By analysing large and diverse patient datasets, including clinical records, genetic information, imaging results and more, AI models excel at discerning subtle patterns and correlations that may elude human observation.[30, 31] This predictive capability spans multiple medical conditions, enabling clinicians to anticipate disease progression, treatment responses and overall prognosis with remarkable accuracy. In healthcare settings, AI-driven predictive analytics play a crucial role in risk stratification by identifying patients at elevated risk for complications or adverse events.[32] Armed with this predictive insight, healthcare providers can implement personalised interventions and allocate resources more efficiently, thereby improving patient outcomes.

For chronic conditions such as diabetes and cardiovascular diseases, AI holds promise in forecasting the likelihood of future complications, thus facilitating preventive measures and timely management strategies.[33] By leveraging AI-powered predictive models, healthcare teams can proactively intervene to mitigate risks and optimise patient care. In cancer care, AI algorithms analyse extensive data including tumour characteristics, treatment responses and patient profiles to predict survival rates, recurrence risks and treatment outcomes.[34, 35] This predictive insight not only aids oncologists in developing tailored treatment plans but also enables optimisation of therapeutic strategies based on individual patient needs, thereby improving overall cancer care quality. The integration of AI in predicting patient outcomes enhances clinical decision-making and contributes to the ongoing paradigm shift toward personalised medicine. By tailoring treatments to individual patient profiles and predicting outcomes with precision, AI empowers healthcare providers to deliver more effective, patient-centred care.

Speeding up diagnostic parameters

AI is at the forefront of revolutionising diagnostic processes in healthcare by significantly improving speed and efficiency, particularly in image-based diagnostics such as radiology and pathology. AI applications play a pivotal role in expediting diagnostic workflows by rapidly analysing and interpreting medical images, including X-rays, MRIs and pathology slides, with unparalleled speed and accuracy.[36, 37] In radiology, AI facilitates rapid detection and interpretation of abnormalities, substantially reducing the time required for diagnostic imaging procedures. By automating image analysis tasks, AI algorithms enable radiologists to efficiently review and interpret large volumes of images efficiently, thereby accelerating the diagnostic process and enabling timely interventions and treatment planning.[6, 17] Similarly, in pathology, AI algorithms revolutionise microscopic image analysis, significantly decreasing the time pathologists spend reviewing and interpreting slides. By automating tedious tasks and providing rapid insights into tissue characteristics, AI expedites diagnosis, enabling pathologists to make timely and accurate diagnoses.[38, 39]

The speed and efficiency with which AI processes and interprets complex medical data not only accelerate diagnosis but also facilitate faster decision-making by healthcare professionals. This rapid turnaround is particularly beneficial in emergency situations or when managing rapidly progressing diseases where prompt action is essential. Furthermore, integrating AI technologies promises to reduce diagnostic turnaround times further and enhance overall healthcare efficiency as these systems advance. By leveraging AI-driven solutions, healthcare institutions can streamline diagnostic processes, improve patient throughput and ultimately deliver more timely and effective care. AI-driven technologies are revolutionising diagnostic workflows in healthcare, significantly improving speed and efficiency in image-based diagnostics such as radiology and pathology. By expediting medical image interpretation and automating tedious tasks, AI accelerates diagnosis, facilitates faster decision-making and ultimately improves patient outcomes.

Quality assurance and standardisation

AI serves as a cornerstone for maintaining quality assurance and standardisation within healthcare, particularly in diagnostic fields such as pathology, radiology and medical imaging. AI applications significantly reduce inter-observer variability and enhance diagnostic accuracy by automating image analysis and pattern recognition tasks.[40, 41] Through automated processes, AI algorithms provide consistent and objective evaluations, mitigating the inherent subjectivity of human interpretation. This AI-driven standardisation not only improves the reliability of diagnostic results but also ensures that patients receive consistent, high-quality care regardless of the interpreting physician. By minimising variability, AI-driven quality assurance processes help identify and correct errors or discrepancies in diagnostic practices, ultimately enhancing patient care and safety.[42] Furthermore, AI-driven quality assurance contributes to the ongoing refinement of AI models through continuous learning cycles. By identifying areas for improvement and incorporating feedback, AI systems evolve to deliver progressively higher levels of diagnostic accuracy and reliability over time.[43] AI-driven standardisation not only streamlines diagnostic practices within healthcare but also holds the potential to facilitate large-scale epidemiological studies. By ensuring that collected and analysed data are uniform and reliable, AI contributes to robust research outcomes and enables more informed decision-making in public health initiatives.[44, 45] AI continues to evolve and mature in maintaining high standards of quality assurance in healthcare. By promoting more reliable and reproducible diagnostic practices across diverse medical settings, AI empowers healthcare professionals to deliver optimal care and improve patient outcomes.

Robotics in surgery

The integration of AI with robotics has ushered in a new era in surgery, transforming traditional procedures while enhancing precision, efficiency and patient outcomes. AI-driven robotic surgical systems have become indispensable tools, augmenting surgeons' capabilities across various disciplines from minimally invasive procedures to complex interventions.[46] AI algorithms embedded in robotic surgical platforms enable real-time data analysis, empowering surgeons to make immediate, patient-specific decisions. This capability enhances surgical precision, reduces error rates and improves postoperative recovery.[47, 48]

By providing surgeons with critical insights and actionable data during procedures, AI-driven robotic systems elevate surgical care quality and patient safety. A key advantage of AI in robotic surgery is its ability to assist surgeons in navigating intricate anatomical structures with unparalleled accuracy. In procedures requiring precise manipulation and dexterity, AI-guided robotic systems provide exceptional control and stability, minimising inadvertent tissue damage and optimising surgical outcomes.[49, 50] Furthermore, AI supports predictive analytics during surgery by leveraging real-time data streams to anticipate potential complications and recommend optimal interventions. By continuously monitoring physiological parameters and surgical variables, AI-driven robotic systems enable proactive interventions, mitigating risks and ensuring a smoother intraoperative experience.[51, 52]

A prime example of AI-enabled robotic surgery is the *da Vinci Surgical System*. This widely adopted platform employs AI to assist surgeons in performing complex procedures with robotic precision. The system's intuitive interface and AI-guided instrumentation facilitate intricate manoeuvres, enabling surgeons to perform tasks with unparalleled accuracy and control.[53, 54] By combining surgeons' expertise with the analytical capabilities of AI-driven robotic systems, the *da Vinci Surgical System* has revolutionised surgical practice, making procedures less invasive, more precise and ultimately safer for patients. As AI technology advances, the integration of robotics and AI in surgery holds tremendous promise for the future. By refining surgical techniques, expanding the scope of minimally invasive procedures and enhancing patient care, AI-driven robotic systems are poised to reshape the surgical landscape in the coming years.[55] The integration of AI with robotics has revolutionised surgery, empowering surgeons with advanced tools to deliver optimal patient care. Through real-time data analysis, precise navigation and predictive analytics, AI-driven robotic systems enhance surgical precision, efficiency and safety, ultimately improving patient outcomes and advancing surgical practice.

The integration of AI and precision medicine

The integration of AI and precision medicine represents a transformative healthcare approach, offering significant potential to revolutionise diagnosis, treatment and patient care. Precision medicine, also known as personalised medicine, focuses on tailoring medical interventions to individual characteristics, including genetic makeup, lifestyle and environmental exposures. AI refers to the simulation of human intelligence processes by machines, especially through algorithms that analyse large datasets to gain insights and make predictions. The combination of these fields presents unprecedented opportunities to improve healthcare delivery and outcomes.[56] At the core of precision medicine is the concept of biomarkers, biological indicators used to identify disease risk, progression and treatment response.[57] AI algorithms excel at analysing complex datasets, including genomic, proteomic and clinical data, to identify relevant biomarkers and patterns often imperceptible to human observers. By leveraging AI, healthcare providers can develop more accurate and reliable biomarker-based tests for disease diagnosis, patient stratification by treatment responsiveness and prediction of disease outcomes.[58]

One area where the integration of AI and precision medicine has demonstrated significant promise is oncology.[59] Cancer is a highly heterogeneous disease characterised by variations in tumour biology and patient characteristics that influence treatment response and prognosis. AI-powered algorithms can analyse multi-omics data, including genomics, transcriptomics and imaging data, to identify molecular signatures associated with distinct cancer subtypes and predict patient responses to various therapies. This capability enables oncologists to tailor treatment plans to individual patients, optimising therapeutic efficacy while minimising adverse effects.[60] Moreover, AI-driven precision oncology platforms facilitate the discovery of novel therapeutic targets and the development of targeted therapies, including immunotherapies. By mining large-scale genomic databases and integrating diverse datasets, AI algorithms identify genetic alterations and pathways driving cancer progression, thereby guiding the development of precision medicines that specifically target these molecular aberrations. This approach has led to the emergence of breakthrough cancer treatments, including PARP inhibitors for BRCA-mutated breast and ovarian cancers and immune checkpoint inhibitors for various malignancies.[61] Beyond oncology, the integration of AI and precision medicine is transforming additional healthcare domains, including cardiology, neurology and infectious diseases. In cardiology, AI algorithms analyse ECG data to detect subtle abnormalities indicative of cardiac conditions, including arrhythmias and ischemia, thereby enabling early intervention and risk stratification.[62, 63] Similarly, in neurology, AI-powered imaging analysis tools assist in the early diagnosis of neurodegenerative diseases, such as Alzheimer's disease and Parkinson disease, by detecting structural and functional brain pathologies that precede clinical symptoms.[64]

In the field of infectious diseases, AI-driven models analyse epidemiological data, pathogen genomic sequences and clinical data from infected individuals to track disease transmission, predict outbreaks and optimise treatment strategies.[65] During the COVID-19 pandemic, AI algorithms played a critical role in accelerating the development of diagnostics, therapeutics and vaccines, thereby enabling rapid responses to the evolving public health crisis.[66] Despite the considerable potential of AI-driven precision medicine, several challenges remain to be addressed. These challenges include ensuring data privacy and security, overcoming barriers to data interoperability and integration, addressing algorithmic bias and interpretability and navigating regulatory and ethical considerations. Furthermore, robust validation and clinical translation of AI-driven models are essential to establish their reliability and effectiveness in real-world healthcare settings. The integration of AI and precision medicine represents a paradigm shift in healthcare, offering unprecedented opportunities to improve patient outcomes, enhance diagnostic accuracy and accelerate the development of personalised therapies. By harnessing AI's capability to analyse vast datasets and generate actionable insights, healthcare providers can deliver more precise, effective and individualised care, thereby ushering in a new era of precision medicine. However, realising the full potential of AI-driven precision medicine requires multidisciplinary collaboration, sustained investment in infrastructure and technology and ongoing efforts to address the technical, regulatory and ethical challenges inherent in this transformative healthcare approach.

Benefits of AI in precision medicine

Personalised treatment

AI holds significant potential to revolutionise customised treatment approaches across diverse medical specialties. By leveraging AI algorithms to analyse extensive patient data, including genomic, clinical and lifestyle information, healthcare providers can tailor treatments to individual patients with unprecedented precision and efficacy.[67] One primary benefit of AI in personalised treatment is its ability to predict treatment responses and outcomes based on patient-specific characteristics. AI algorithms can identify biomarkers and patterns within patient data that correlate with treatment efficacy, enabling clinicians to select the most appropriate therapy for each patient. For example, in oncology, AI-driven models analyse tumour genomic profiles to predict which patients are likely to respond to specific cancer therapies, including targeted therapies and immunotherapies.[68] This personalised approach maximises treatment efficacy while minimising adverse effects, thereby improving patient outcomes and quality of life. Moreover, AI facilitates the discovery of novel therapeutic targets and the development of targeted therapies tailored to individual patient profiles. By mining large-scale genomic and proteomic datasets, AI algorithms identify genetic alterations and molecular pathways driving disease progression, thereby enabling the development of precision medicines that specifically target these molecular aberrations.[69, 70] This approach has led to the emergence of breakthrough treatments for diverse diseases, including cancer, cardiovascular disorders and rare genetic conditions. Furthermore, AI-driven personalised treatment approaches enable clinicians to optimise treatment regimens and dosages based on real-time patient data and feedback. By continuously analysing patient responses to treatment and adjusting therapy parameters accordingly, AI algorithms ensure that patients receive the most effective and personalised care throughout their treatment journey.[71] Overall, the integration of AI in personalised treatment holds the promise of revolutionising healthcare delivery by providing tailored and effective therapies that address the unique needs of each patient. By harnessing AI to analyse patient data and derive actionable insights, healthcare providers can optimise treatment outcomes, minimise adverse effects and improve patient satisfaction and quality of life. As AI technology continues to advance, the potential for personalised treatment approaches to transform healthcare delivery and outcomes will expand.

Early disease detection

AI plays a crucial role in early disease detection by using advanced algorithms to analyse large datasets and spot subtle patterns that indicate disease onset. One key advantage of AI in early detection is its capacity to sift through complex datasets, including genomic, proteomic, imaging and clinical data, to uncover biomarkers and signatures associated with diseases at their earliest stages.[72] In medical imaging, AI algorithms analyse radiological images, such as X-rays, MRIs and CT scans, to detect abnormalities and lesions indicative of disease. For example, AI-powered mammography and lung cancer screening tools assist radiologists in identifying suspicious findings, such as tumours or nodules, at early stages when treatment is most effective.[73] Moreover, AI-driven diagnostic tools analyse biochemical markers and physiological data to detect changes indicative of disease progression or risk. For instance, AI algorithms analyse blood glucose levels, heart rate variability and other physiological parameters to predict the onset of conditions such as diabetes, cardiovascular diseases and neurodegenerative disorders.[74, 75] By enabling early detection and intervention, AI-powered systems have the potential to significantly improve patient outcomes, reduce healthcare costs and alleviate the burden on healthcare systems. As AI technology continues to advance, the scope and accuracy of early disease detection tools will further improve, ushering in a new era of preventive and personalised medicine.

Improved diagnosis

AI enhances diagnostic accuracy by analysing extensive datasets to identify subtle patterns indicative of disease. AI-driven algorithms, trained on diverse datasets, excel in medical imaging analysis, pathology interpretation and diagnostic decision-making. By integrating AI into clinical practice, healthcare professionals benefit from augmented diagnostic capabilities, leading to earlier and more accurate disease detection and characterisation.[76] Through continuous learning and refinement, AI contributes to improved patient outcomes and optimised healthcare delivery. Enhanced Drug Discovery: AI accelerates the drug discovery process by analysing large datasets to identify potential drug targets, predict drug interactions and optimise pharmacotherapies. This leads to the development of more effective and targeted treatments.[77]

Precision oncology

AI-driven precision oncology represents a transformative approach in cancer care, employing advanced algorithms to analyse genomic, proteomic and clinical data to tailor treatment strategies for individual patients. By integrating AI into oncology practice, healthcare providers can identify molecular signatures linked to distinct cancer subtypes, predict patient responses to specific therapies and optimise treatment regimens. AI models analyse complex genomic data to uncover genetic alterations and pathways driving cancer progression, guiding the development of targeted therapies and immunotherapies.[78] Additionally, AI-powered imaging analysis tools assist in tumour detection, characterisation and response assessment, facilitating personalised treatment planning. The implementation of AI-driven precision oncology has led to significant advancements in cancer treatment, yielding improved outcomes and reduced toxicity for patients. By selecting the most effective therapies based on molecular profiles and predicting treatment responses, AI enhances treatment efficacy while minimising adverse effects. Furthermore, AI-driven approaches enable the discovery of novel therapeutic targets and the development of innovative treatment modalities, leading to personalised and more effective cancer care.[79, 80] As AI technology continues to evolve, the potential of AI-driven precision oncology to transform cancer diagnosis, treatment and outcomes remains unparalleled, ushering in a new era of precision medicine in oncology.

Public health surveillance

Public health surveillance entails monitoring, analysing and interpreting health-related data to detect and control disease spread, assess health trends and guide public health interventions. AI is transforming public health surveillance by enhancing the speed, accuracy and efficiency of data analysis and interpretation. AI-powered algorithms analyse diverse datasets: namely epidemiological data, pathogen genomic sequences, clinical records and social media posts, to identify patterns and trends indicative of disease outbreaks and public health threats. For example, AI analyses real-time data streams from sources such as electronic health records, hospital admissions and symptom reporting systems to detect early warning signs of infectious disease outbreaks. Moreover, AI facilitates predictive modelling and risk assessment, enabling public health authorities to anticipate disease spread, allocate resources efficiently and implement targeted interventions to mitigate health risks.[81] AI-driven predictive analytics forecast disease trajectories, identify high-risk populations and optimise vaccination campaigns and resource allocation. Additionally, AI enhances disease surveillance through automated data processing and anomaly detection, enabling rapid identification of unusual patterns or clusters that may indicate emerging threats or outbreaks.[82] AI-powered surveillance systems continuously monitor diverse data sources, flag anomalies in real-time and enable prompt investigation and response.[83] Overall, integrating AI into public health surveillance holds immense promise for enhancing disease detection, response and prevention efforts. By leveraging AI-driven analytics and predictive modelling, public health authorities improve situational awareness, allocate resources more efficiently and implement timely interventions to protect population health and prevent infectious disease spread.[84] As AI technology advances, the potential of AI-driven public health surveillance to revolutionise global disease control and prevention efforts is vast.

Challenges of AI in precision medicine

Data quality and availability

A primary challenge for AI in precision medicine is its reliance on high-quality, diverse datasets for training and validation; however, healthcare data frequently fail to meet these standards. Healthcare data are often fragmented across multiple systems, institutions and formats, complicating access and integration into AI models. Moreover, healthcare data may be incomplete, with gaps or missing values that compromise AI algorithm performance.[85] Additionally, data in healthcare settings are subject to various biases, such as demographic disparities, clinical variability and sampling biases that can skew AI-driven analyses and predictions.[86] Addressing these challenges requires concerted efforts to improve data quality, promote data sharing and interoperability and mitigate biases to enable the development and deployment of robust, reliable AI models in healthcare.

Data privacy and security

Data privacy and security pose significant challenges for AI in healthcare. Protecting patient privacy and ensuring the confidentiality of sensitive health information remain paramount concerns in healthcare settings. AI algorithms require access to large volumes of patient data for training and analysis, raising concerns about data breaches and unauthorised access. Compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) imposes strict requirements on data handling, storage and sharing, thereby complicating AI development and deployment. Additionally, the inherent complexity of AI algorithms and their reliance on sensitive patient data increase the risk of vulnerabilities and cyberattacks, necessitating robust cybersecurity measures and ethical guidelines to safeguard patient privacy and prevent data breaches in AI-driven healthcare applications. Algorithm Bias and Interpretability: AI models may inherit biases present in training data, resulting in disparities in healthcare outcomes. Furthermore, the complexity of AI algorithms renders their decisions difficult to interpret and explain, raising concerns about trust and accountability.[87, 88]

Regulatory and ethical considerations

Regulatory and ethical considerations present significant challenges for AI in healthcare. The rapid advancement of AI technology has outpaced the development of regulatory frameworks, resulting in uncertainty and inconsistency in oversight. Ethical concerns regarding transparency, accountability and fairness in AI-driven decision-making arise, particularly in sensitive domains such as diagnosis, treatment and patient care.[86, 89] Balancing innovation with patient safety and ethical principles necessitates clear guidelines and standards for AI development, deployment and governance.[90] Collaboration among stakeholders such as policymakers, regulators, healthcare professionals and technology developers is crucial to tackle these challenges and promote the responsible and ethical use of AI in healthcare.

Integration with clinical workflow

Integrating AI-driven tools into clinical workflows presents logistical challenges, including interoperability with EHRs, user interface design and healthcare professional training. Seamless integration with existing systems and workflows is essential to ensure efficient adoption and utilisation of AI tools in clinical practice. User-friendly interfaces and intuitive design are crucial to facilitate acceptance and usability among healthcare providers. Furthermore, comprehensive training and ongoing support are necessary to empower healthcare professionals with the skills and confidence required to effectively leverage AI-driven tools in patient care, thereby optimising their impact on clinical decision-making and patient outcomes.[91]

Cost and accessibility

AI-driven precision medicine requires significant investment in technology, infrastructure and training, which presents major challenges related to cost and accessibility. Adopting AI technologies often requires substantial financial resources to acquire advanced hardware, software and data infrastructure, as well as ongoing maintenance and support costs.[92] Furthermore, healthcare organisations must dedicate resources to staff training and education to ensure competency in the effective use of AI-driven tools. However, the cost of implementing AI-driven precision medicine extends beyond initial investments to include ongoing operational expenses, such as data management, algorithm refinement and regulatory compliance.[93] These financial considerations may pose barriers to adoption, particularly for healthcare institutions with limited budgets or competing priorities. Moreover, ensuring equitable access to AI-driven healthcare solutions is essential for addressing disparities in healthcare delivery. Underserved communities, including those in rural areas and low-income populations, may face challenges accessing AI technologies due to financial constraints, limited infrastructure and a lack of technical expertise.

Efforts to promote inclusivity and accessibility in AI-driven healthcare solutions are essential to bridging the digital divide and ensuring that all patients benefit from precision medicine's potential to improve health outcomes and reduce disparities.[94, 95] Collaboration among stakeholders, government agencies, healthcare organisations, technology providers and community leaders is essential for addressing these challenges and promoting the widespread adoption of AI-driven precision medicine while ensuring it remains affordable and accessible for everyone. Solving these issues requires teamwork among healthcare participants, including clinicians, researchers, policymakers, technology developers and patients. By working together to overcome these obstacles, stakeholders can unlock the full potential of AI and precision medicine to improve patient outcomes, enhance healthcare delivery and advance medical practice.

Case studies and examples

IBM Watson for Genomics

IBM Watson for Genomics is an AI-driven platform that analyses genomic data to assist oncologists in identifying personalised treatment options for cancer patients. A study published in *JAMA Oncology* evaluated the performance of *IBM Watson for Genomics* in providing treatment recommendations for cancer patients based on genomic analysis. The study found that Watson's recommendations were concordant with those of a multidisciplinary tumour board in 99 % of cases, demonstrating the platform's capacity to support clinical decision-making in precision oncology.[96] Another case study involves *DeepMind Health's AI* system for retinal disease detection. *DeepMind Health* developed an AI system that analyses retinal images to detect signs of diabetic retinopathy, a leading cause of blindness. The performance of *DeepMind's* AI system was evaluated in detecting diabetic retinopathy from retinal images. They found that the AI system achieved high sensitivity and specificity in detecting diabetic retinopathy, outperforming human experts in some instances. The AI system's ability to accurately diagnose diabetic retinopathy demonstrates its potential to improve early disease detection and intervention in ophthalmology.[97]

Electronic health record data can be used to identify clinical predictors of heart failure exacerbation. The model accurately predicted heart failure exacerbations up to 30 days in advance, enabling timely interventions and preventive strategies to improve patient outcomes.[4] AI-Driven drug discovery: Utilises AI algorithms to accelerate the drug discovery process, depicted in Figure 3. A study employed AI-driven approaches to design novel small-molecule inhibitors targeting DDR1 kinase, which is implicated in fibrotic diseases. It demonstrated that AI-driven drug discovery can

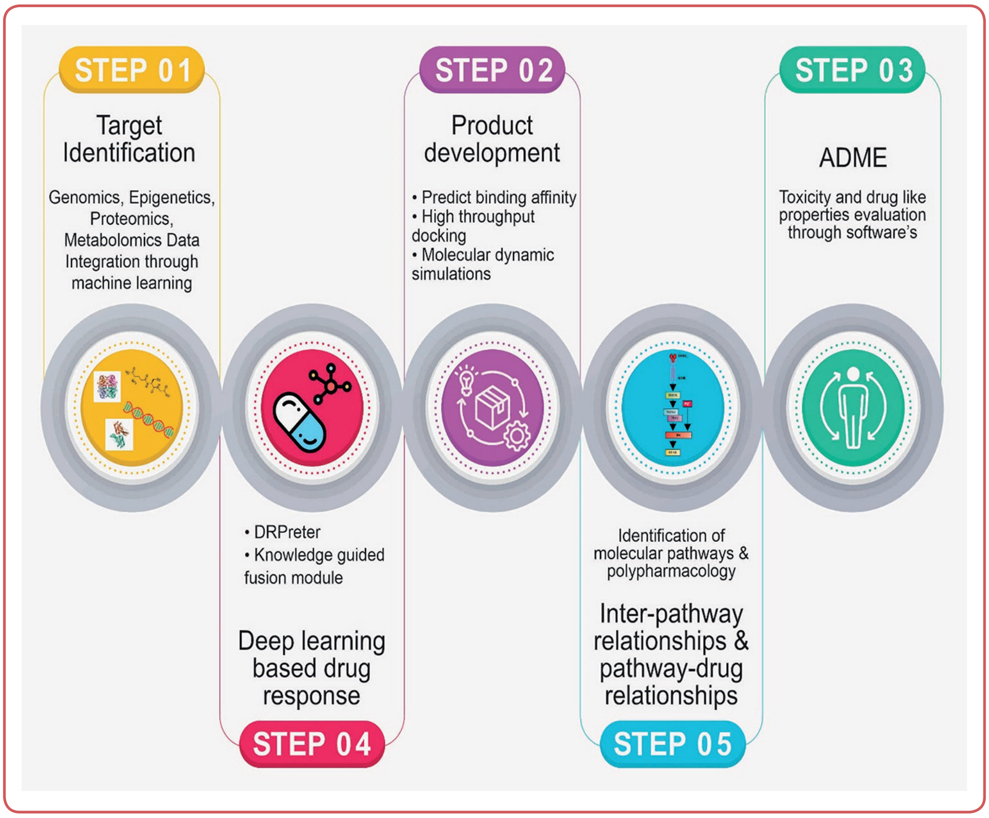

Figure 3: Artificial intelligence (AI) has optimised the drug design and development process. AI also helps identify drug targets, enabling the design of compounds specifically aimed at these targets. Molecular docking is used to assess the binding affinity between the proposed drug and its target. Subsequently, molecular dynamics simulations evaluate the stability of the drug–target complex. Additionally, ADMET analysis is carried out to examine the proposed drug's absorption, distribution, metabolism, excretion and toxicity properties. ADMET: absorption, distribution, metabolism, excretion and toxicity analysis;

significantly expedite the identification of potential drug candidates compared to traditional methods, highlighting its potential to revolutionise the drug development pipeline.[98] This illustrates the successful application of AI in precision medicine across diverse healthcare domains, including oncology, ophthalmology, cardiology and drug discovery. By leveraging AI-driven approaches, researchers and clinicians enhance disease detection, treatment selection and patient outcomes, thereby paving the way for more personalised and effective healthcare interventions.

Future prospects of AI and precision medicine

The future of AI and precision medicine offers great potential to transform healthcare delivery, diagnosis, treatment and personalised patient care. Ongoing research and technological progress continue to fuel innovation in AI-based precision medicine, leading to breakthroughs that will shape the future of healthcare, as shown in Figure 4. One active area of research is the development of AI-driven predictive analytics models for disease prevention and early intervention. These models leverage machine learning algorithms to analyse diverse datasets including genomic, clinical and environmental data to identify individuals at risk of developing various diseases. By predicting disease onset or progression before symptom manifestation, AI-driven predictive analytics enable proactive interventions and personalised preventive strategies, ultimately improving health outcomes and reducing healthcare costs.[99] Technological advancements in AI algorithms, including deep learning and natural language processing, are enhancing the accuracy and reliability of AI-driven diagnostics and treatment recommendations. Deep learning algorithms can analyse complex medical imaging data such as MRI and CT scans with unprecedented precision, assisting radiologists and pathologists in diagnos-

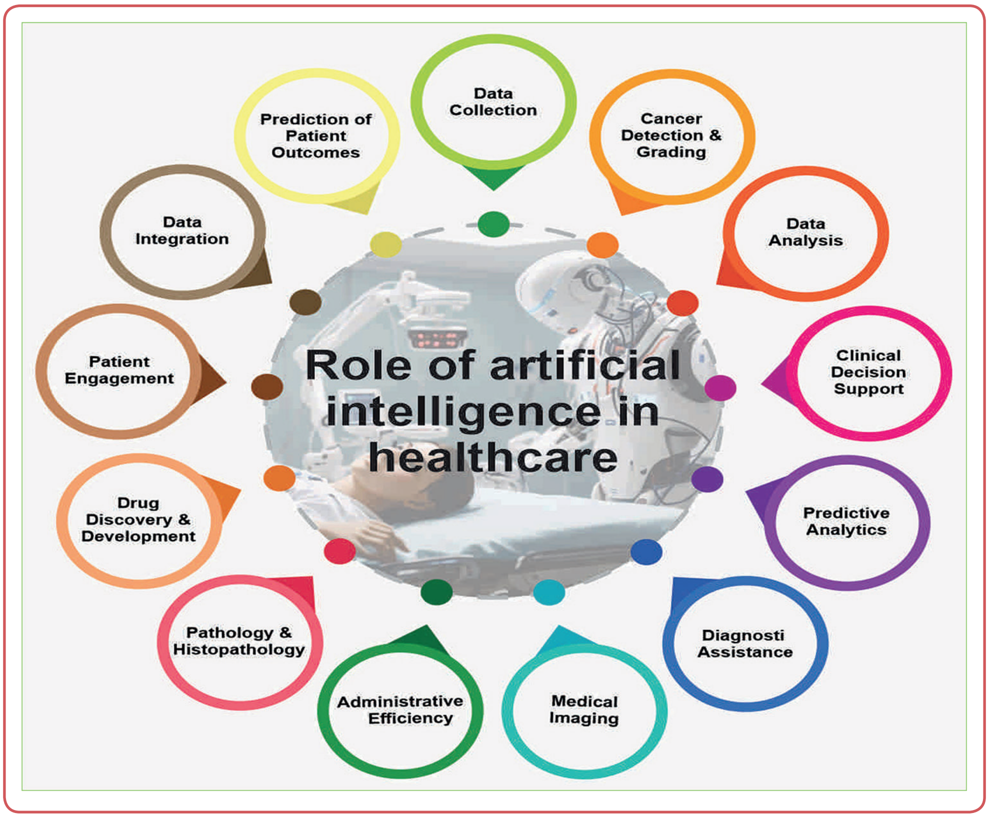

Figure 4: The various diagram components highlight the key future developments driven by artificial intelligence (AI)

ing diseases at earlier stages with greater accuracy. Furthermore, natural language processing algorithms can extract valuable insights from unstructured clinical notes and scientific literature, facilitating evidence-based decision-making and advancing medical knowledge.[100]

Another area focuses on integrating AI with emerging technologies such as genomics, proteomics and wearable devices to enable personalised and proactive healthcare. AI-driven genomic analysis tools interpret vast quantities of genomic data to identify genetic variants associated with disease risk, treatment response and drug metabolism, thereby guiding precision medicine approaches tailored to individual patients.[101] Additionally, wearable devices equipped with AI algorithms continuously monitor physiological parameters, detect early signs of disease or deterioration and provide real-time feedback to patients and healthcare providers, thereby empowering individuals to take proactive control of their health.[102] The combination of AI and precision medicine holds the potential to revolutionise healthcare delivery by shifting toward a more patient-centred, preventive and proactive approach. By leveraging AI-driven insights and personalised treatment strategies, healthcare providers can optimise resource allocation, improve clinical outcomes and enhance patient satisfaction and engagement. Furthermore, AI-driven precision medicine has the potential to address healthcare disparities by delivering tailored interventions to underserved populations and reducing inequities in access to quality care.[103] The future of AI and precision medicine is characterised by ongoing research, technological advancements and breakthroughs that will continue to shape the healthcare landscape (Figure 4).

Ethical considerations of AI in precision medicine

The integration of AI into precision medicine raises several ethical considerations that must be carefully addressed to ensure the responsible and equitable deployment of these technologies. Key ethical issues include data privacy, informed consent, transparency, fairness and accountability. AI-driven precision medicine relies on vast amounts of sensitive health data, including genomic, clinical and lifestyle information. Protecting patient privacy and confidentiality is paramount to maintaining trust and ensuring compliance with regulations such as the HIPAA and the European Union's GDPR. Healthcare organisations must implement robust data encryption, anonymisation techniques and access controls to safeguard patient data from unauthorised access or misuse.[104]

Informed consent is essential when utilising patient data for artificial intelligence-driven precision medicine research or clinical applications. Patients should be fully informed about how their data will be used, the potential risks and benefits and their rights concerning data sharing and privacy. Obtaining explicit consent from patients ensures respect for individual autonomy and fosters trust among patients, healthcare providers and researchers.[105] AI algorithms employed in precision medicine should be transparent and explainable to foster understanding and trust among all stakeholders. Clinicians and patients should have access to detailed information regarding how AI models generate predictions or recommendations, including data inputs, decision-making processes and potential biases. Transparent artificial intelligence systems enable clinicians to validate predictions, identify limitations and make well-informed decisions regarding patient care.[106]

AI-driven precision medicine must address issues of bias and fairness to ensure equitable healthcare delivery. Biases inherent in training data or algorithms can lead to significant disparities in diagnosis, treatment and outcomes among diverse demographic groups. It is imperative that developers rigorously evaluate AI models for bias, mitigate such biases through algorithmic adjustments or data pre-processing techniques and actively promote fairness and inclusivity in AI-driven healthcare solutions.[2] Establishing precise accountability mechanisms is essential to address liability and responsibility in AI-driven precision medicine. Healthcare organisations, developers and regulators must collaboratively develop comprehensive guidelines and standards to ensure the responsible development, deployment and monitoring of AI systems. Transparent reporting of artificial intelligence performance metrics, regular audits and mechanisms for addressing errors or adverse events collectively ensure accountability and mitigate potential harm to patients.[107] Therefore, addressing the ethical implications of AI in precision medicine requires a comprehensive approach that prioritises data privacy, informed consent, transparency, fairness and accountability. By adhering to these ethical principles and guidelines, stakeholders can ensure the responsible and equitable deployment of AI technologies in healthcare, thereby ultimately benefiting patients and advancing both medical research and clinical practice.

Future directions for next-generation AI

Next-generation AI is expected to redefine the scope of precision medicine through the convergence of advanced computational models, multimodal data integration and ethical innovation. The future of AI in healthcare will emphasise explainable and transparent AI systems, ensuring that clinical decision-making remains interpretable and accountable. Integrating generative AI and large language models (LLMs) with clinical and molecular data will enable intelligent, context-aware diagnostics and personalised therapeutic design.

Another critical direction involves multimodal learning frameworks capable of combining genomics, imaging, EHRs and real-time wearable data into unified predictive models. Such integration will enhance disease stratification, early detection and individualised treatment recommendations. Moreover, federated learning and privacy-preserving computational methods will facilitate secure cross-institutional data sharing, accelerating collaborative research while maintaining patient confidentiality.

Future AI systems will also leverage quantum computing and bioinformatics-driven simulations to accelerate drug discovery and optimise molecular design at an unprecedented scale. The development of adaptive, self-learning algorithms capable of continuously updating from new data streams will further improve diagnostic precision and therapeutic outcomes. Ethical frameworks, human–AI collaboration models and inclusive datasets will remain essential to ensure equity and trust in next-generation AI applications.

These advancements mark a shift from static analytical tools to dynamic, learning healthcare ecosystems, where AI not only augments clinical intelligence but actively participates in evolving medical knowledge and personalised care strategies.

Conclusion

This review highlights the scientific advances in combining AI with precision medicine as a transformative approach for personalised healthcare. By carefully reviewing recent progress, it demonstrates how AI, mainly through machine learning and deep learning algorithms, enables the extraction of clinically valuable insights from complex, multidimensional data. Its main contribution is an in-depth analysis of AI applications in genomics, diagnostics, therapeutics and clinical decision-making, providing a clear framework for how AI is changing the field of precision medicine. This new perspective links computational progress with clinical practice, offering a guide for the future development of personalised medicine in the age of AI.

Ethics

This study was a secondary analysis based on the currently existing data and did not directly involve with human participants or experimental animals. Therefore, the ethics approval was not required in this paper.

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Conflicts of interest

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Data access

The data that support the findings of this study are available from the corresponding author upon reasonable individual request.

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