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The impact of artificial intelligence on precision medicine and personalized oncology: A systematic review with narrative synthesis

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ABSTRACT

Background: The use of artificial intelligence (AI) in cancer treatment attempts to improve precision and customization. This integration could enhance treatment outcomes, reduce side effects, and optimize healthcare resource allocation as cancer continues to climb globally.

Aims: This study examines how AI advances personalized oncology by predicting treatment responses, improving outcomes, and addressing ethical and privacy challenges.

Methods: The study conducted a systematic review of AI applications in personalized oncology, synthesizing research on machine learning (ML) and deep learning (DL) in diagnostics, prognostics, and treatment personalization. It reviewed AI's role in analyzing multi-omics, clinical, and imaging data for cancer therapy selection. Primary data analysis using Smart PLS software further assessed AI's effectiveness in treatment recommendations, emphasizing the need for data standardization and validation for clinical integration.

Results: This review found that predictive modeling with biomarkers, multi-omics, and histopathology data enables AI to analyze complex cancer datasets, enhancing diagnostic and treatment outcomes. DL and ML contribute to personalized oncology by predicting patient responses and identifying treatment targets. However, challenges such as data standardization, algorithm transparency, and ethical considerations need to be addressed to ensure the responsible use of AI in this field.

Conclusion: The potential of AI to enhance the precision of cancer treatment and personalize patient care while acknowledging challenges such as data transparency, ethical sharing, and collaboration is highly likely. Ongoing research and integrating various ML methods are crucial for successfully implementing these advancements in clinical practice.

Keywords: personalized oncology, artificial intelligence, machine learning, deep learning, multi-omics

INTRODUCTION

The integration of artificial intelligence (AI) into cancer management is transforming personalized medicine. Recent advancements in machine learning (ML) and deep learning (DL) enable precise predictions of treatment responses and outcomes for cancer patients [1-3]. This shift emphasizes the need to customize treatment plans based on individual characteristics, tumor biology, and genetic profiles. AI's ability to analyze extensive datasets is revolutionizing breast cancer diagnosis and treatment, leading to enhanced patient outcomes [4-6].

Recent literature highlights AI's remarkable capacity to predict treatment responses based on genetic and molecular profiles, yielding tailored therapeutic approaches [7, 8]. For instance, AI algorithms can process complex omics data to identify patterns linked to treatment efficacy, particularly in breast cancer management, where they have demonstrated high accuracy in predicting patient survival [9-12].

AI systems significantly advance precision medicine by integrating multi-omics data (genomic, transcriptomic, proteomic, etc.), thus providing a comprehensive view of tumor biology and guiding personalized treatment strategies. This approach also facilitates the identification of unique biomarkers for therapy selection [7].

Additionally, AI is not limited to initial treatment planning but also enhances ongoing monitoring and adaptation of treatment regimens [13, 14]. AI-driven predictive modeling can evaluate patient responses in real time, allowing clinicians to modify therapies in accordance with the most recent data. In the management of complex cancers, where patient responses can fluctuate substantially over time, this dynamic treatment approach is particularly advantageous [9].

Despite these promising developments, challenges remain in the widespread adoption of AI technologies in clinical practice. Addressing critical issues such as data quality, algorithm transparency, and the need for robust validation studies is essential [11, 15]. Ethical considerations surrounding AI-driven decision-making and patient data privacy also require attention [16]. To fully realize the potential of AI in

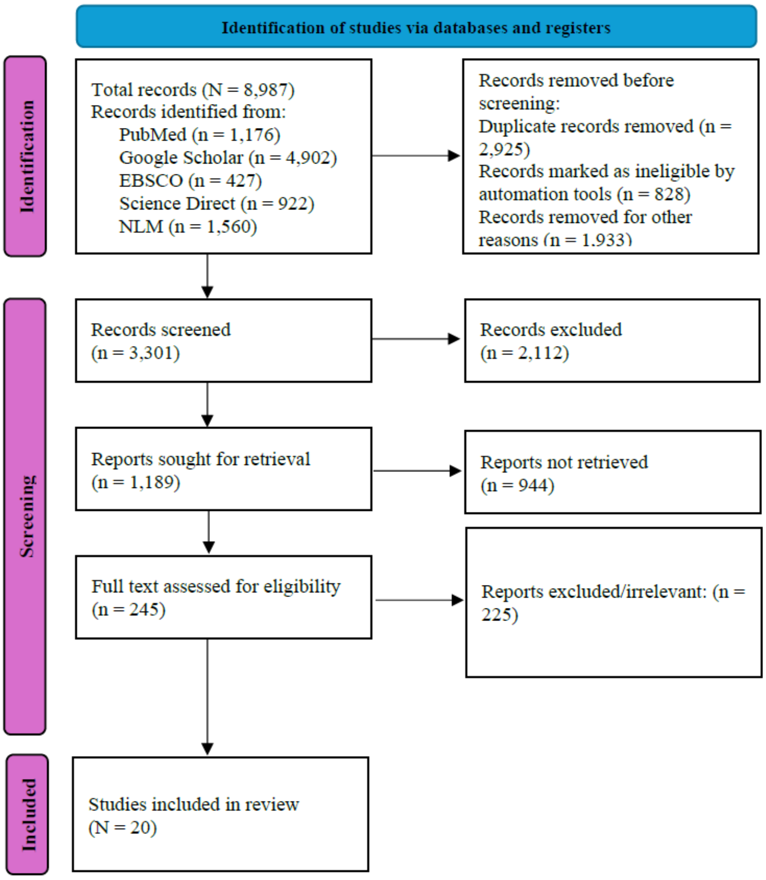

Figure 1. PRISMA flow chart for the included studies (Source: Author's own elaboration)

enhancing patient care and transforming breast cancer management, it will be imperative to conduct ongoing research and collaborate with oncologists, regulatory bodies, and AI experts as the field continues to develop. The literature also emphasizes significant ethical and practical considerations, despite the immense potential of AI in personalized oncology [17, 18]. The successful incorporation of AI tools into clinical practice is contingent upon the resolution of critical issues, including data privacy, algorithm transparency, and the necessity of rigorous validation.

Thus, the purposes of this systematic review were to:

1. Evaluate the accuracy of ML models in predicting individual patient responses to cancer treatments.
2. Measure the reduction in adverse drug reactions or treatment-related complications through AI-guided therapy selection based on individual biological profiles.
3. Identify key ethical, data privacy, and transparency challenges in AI-driven oncology, emphasizing the need for rigorous validation and collaboration among healthcare providers, regulators, and AI researchers to fully integrate these tools into clinical practice.

METHODS

Design

This systematic review followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [19].

Screening process

A comprehensive literature search was conducted across Scopus, IEEE Xplore, PubMed, and Google Scholar. Keywords related to AI and oncology, personalized oncology, cancer treatment, precision medicine, ML, DL, and AI's role in patient response to oncology treatments were used, with Boolean operators to refine the search. Two reviewers independently screened the retrieved article titles and abstracts.

During the screening phases, studies were removed due to duplicates, irrelevance to AI in oncology or personalized medicine, non-English publications, or publication dates outside the specified range (pre-2019). Additional exclusions involved non-peer-reviewed articles (e.g., editorials, letters), studies lacking human subjects or AI/ML focus, insufficient data, or inaccessible full texts. Others were excluded for discussing only ethical/regulatory issues, mismatched outcomes (e.g., no treatment response metrics), outdated AI methods, non-generalizable demographics, or failure to meet PICOS criteria. Low-quality studies with high bias risks (e.g., small samples) were also removed to ensure methodological rigor and relevance to the review's objectives. Then, Full-text articles of potentially eligible studies were evaluated against inclusion criteria, with the final selection of 20 articles detailed in **Figure 1**.

Inclusion and Exclusion Criteria

The inclusion criteria involved peer-reviewed articles, clinical trials, and meta-analyses focused on the use of AI in personalized healthcare. Relevant studies were identified through a systematic review of abstracts and full texts, followed by organized data extraction. The inclusion criteria were:

(a) emphasis on personalized oncology, AI, and precision medicine,

(b) publication in English, and

(c) publication dates between 2019 and 2024.

Studies unrelated to AI in oncology, non-English publications, works published before 2019, editorials, letters, and reports were excluded.

Data Synthesis Strategy

This systematic review of AI in personalized oncology for precision medicine used a structured data synthesis to effectively integrate findings from the selected studies. For studies with varied methodologies, outcomes, or AI applications, a narrative synthesis was applied. Studies were organized into key themes, such as AI's role in oncology diagnosis, treatment, and patient monitoring. The synthesis process involved summarizing descriptions, identifying thematic links, and interpreting findings to provide a well-rounded understanding of AI's impact across different cancer types.

Quality Assessment Frameworks

The study employed standardized frameworks to rigorously evaluate the methodological quality and risk of bias of the included studies. For randomized controlled trials, the Cochrane risk of bias tool was used to assess bias across domains such as randomization, deviations from intended interventions, and selective reporting [20]. Non-randomized studies, including cohort and case-control designs, were evaluated using the Newcastle-Ottawa scale, which examines selection, comparability, and outcome assessment [21]. Diagnostic accuracy studies were appraised with QUADAS-2, focusing on patient selection, index tests, and reference standards [22]. Additionally, the PRISMA checklist ensured transparency in reporting systematic review methods [19].

RESULTS

Following PRISMA protocol, a comprehensive search conducted across Scopus, IEEE Xplore, PubMed, and Google Scholar identified a total of 3,987 records, as depicted in **Figure 1**. Following the removal of 1,522 duplicate entries through both EndNote and manual verification, 2,465 unique records remained for title and abstract screening. Out of these, 2,112 records were excluded due to irrelevance, such as those not focusing on oncology, not utilizing AI methods, or involving animal studies. Consequently, 353 full-text articles were further scrutinized for eligibility. Of these, 225 were eliminated for various reasons: 28 were not published in English, 41 were published before 2019, 89 lacked primary data or systematic review methodology, and 67 did not sufficiently focus on personalized oncology. Ultimately, 20 studies met all inclusion criteria and were incorporated into the qualitative synthesis, as shown in **Table 1**. The inter-rater agreement during the screening process was high, with a Cohen's κ of 0.82.

Table 1. Matrix of included studies (N = 20)

Study	Title	Type	Country/sample size	Objective(s)	Main results	Conclusion
[23]	Advances in artificial intelligence to predict cancer immunotherapy efficacy	Review article	The study does not specify a particular sample or country as it reviews various research findings and methodologies in the field of AI and cancer immunotherapy.	The main objective of the study is to explore the advancements in AI technologies for predicting the efficacy of cancer immunotherapy, highlighting the potential benefits, challenges, and future directions in this area.	The study discusses various AI models that utilize multi-omics data, histopathological images, and other biomarkers to predict patient responses to immunotherapy. It identifies challenges such as the scarcity of prospective trials, biases in existing studies, and the need for standardized datasets and code sharing.	The authors conclude that while AI holds significant promise for enhancing the precision of cancer immunotherapy predictions, there are critical challenges that need to be addressed, including improving experimental design transparency, ensuring ethical data sharing, and promoting the integration of multi-omics data to create more individualized treatment approaches.
[3]	AI-based personalized treatment recommendation for cancer patients	Original research article (descriptive and analytical study using Smart PLS software for data analysis)	International collaboration (Greece and United Kingdom affiliations). Sample size: Not explicitly stated in the abstract or methodology. The study analyzed primary data but did not specify the number of participants or datasets.	To explore the applications, benefits, and challenges of AI in personalized cancer treatment. To evaluate how AI integrates genomic profiling, medical imaging, and patient data to recommend tailored therapies. To assess the ethical and practical implications of AI-driven oncology.	Demonstrated efficacy in early cancer detection (e.g., image analysis, genomic profiling), treatment personalization, and drug discovery. Statistical analysis: Descriptive statistics showed mean values for AI (1.571), personalized treatment recommendations (PTR: 1.653), and cancer patients (CP: 1.551). Correlation analysis revealed a 100% significant relationship between AI and PTR, but negative correlations between CP and PTR (-0.067).	AI significantly enhances personalized cancer care by leveraging genomic data, predictive analytics, and continuous learning. However, its success depends on collaboration with healthcare professionals and addressing ethical challenges. The study advocates for AI as a complementary tool to human expertise, aiming to improve treatment outcomes and patient empowerment in oncology.
[4]	Artificial intelligence aids in development of nanomedicines for cancer management	Review article	The study does not specify a sample size as it is a review of existing literature; it encompasses various studies from multiple countries.	To elaborate on the advances in AI-enabled nanomedicines in cancer management and their application in diagnosis, monitoring, and therapy, as well as in precision medicine development.	The review discusses how AI can transform healthcare by realizing acquisition and analysis of large datasets, tailoring precision nanomedicines for cancer management. AI-enabled nanotechnology can improve the accuracy of molecular profiling and early diagnosis, optimize the design pipeline of nanomedicines, achieve effective drug synergy, and decrease nanotoxicity, thereby enhancing target-ability, personalized dosing, and treatment potency.	AI technologies and their integration with nanomedicines have allowed improvements in the accuracy of cancer detection, enhancement of anti-cancer treatment effectiveness, and enabling post-treatment monitoring of patients. AI shows great potential in the design and development of nanomedicines, and continuous efforts in developing AI algorithms and computer models will revolutionize the design processes of nanomedicines for their application in oncology.

Table 1 (Continued). Matrix of included studies (N = 20)

Study	Title	Type	Country/sample size	Objective(s)	Main results	Conclusion
[8]	Artificial intelligence assists precision medicine in cancer treatment	Review and analysis of existing literature on the application of AI in precision medicine for cancer treatment.	The study encompasses various research articles and data from multiple countries, focusing on global advancements in AI applications in oncology.	To explore how AI can enhance precision medicine in cancer treatment by integrating multi-omics data, improving biomarker discovery, and personalizing therapeutic strategies.	The study highlights significant advancements in AI methodologies, including machine learning and deep learning, that facilitate the analysis of complex cancer data. It emphasizes the role of AI in identifying biomarkers, predicting treatment responses, and optimizing clinical decision-making.	The integration of AI into cancer treatment represents a transformative approach that enhances the precision of therapies, ultimately leading to improved patient outcomes and personalized care strategies. The study underscores the potential of AI to bridge gaps in current cancer treatment paradigms.
[11]	Artificial intelligence for clinical oncology	The study employed Perspective design.	The study utilized biopsy specimens from patients in the United States.	To propose a pathway of clinical cancer care touchpoints for narrow-task AI applications, review a selection of applications, describe the challenges faced in the clinical translation of AI and propose solutions, and suggest paths forward in weaving AI into individualized patient care.	Clinical oncology is experiencing rapid growth in data that are collected to enhance cancer care. With recent advances in the field of AI, there is now a computational basis to integrate and synthesize this growing body of multi-dimensional data, deduce patterns, and predict outcomes to improve shared patient and clinician decision making.	Increasing data streams and advances in computational algorithms have positioned AI to improve clinical oncology via rigorously evaluated, narrow-task applications interacting at specific touchpoints along the cancer care path. Further development of AI applications for cancer care should focus on clinical validity, utility, and usability.
[12]	Artificial intelligence in cancer research and precision medicine	Review article	Not specified	To survey a broad spectrum of publications and studies that capture the breadth and versatility of AI applied to oncology. To describe m nge from those with prospective utilization in the clinic to models that drive research and discovery.	AI is rapidly reshaping cancer research and personalized clinical care. AI applications range from detection and classification of cancer, to molecular characterization of tumors, drug discovery and repurposing, and predicting treatment outcomes.	AI is driving a shifting paradigm in cancer care.
[29]	Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine	Review of multiple AI and ML-based approaches and algorithms in healthcare.	The study does not specify a particular sample or country as it reviews various approaches and applications globally.	To highlight recent contributions and effectiveness of AI and ML in developing computational systems aimed at improving healthcare and precision medicine.	The study discusses various AI and ML approaches, emphasizing the potential of deep learning algorithms in healthcare applications. It identifies challenges such as data integration, privacy concerns, and the need for ethical considerations in AI deployment.	The authors conclude that while deep learning is a prominent trend in AI applications for healthcare, a diverse range of machine learning algorithms should be considered to effectively address specific healthcare challenges. The right approach and algorithm selection are crucial for developing effective solutions in precision medicine.
[2]	Artificial intelligence-assisted selection and efficacy prediction of antineoplastic strategies for precision cancer therapy	Review article	PR China	To summarize emerging approaches, relevant datasets, and open-source software of AI and show how to integrate them to address problems from clinical oncology and cancer research.	The review summarizes emerging approaches, relevant datasets, and open-source software of AI and shows how to integrate them to address problems from clinical oncology and cancer research. It focuses on the principles and procedures for identifying different antitumor strategies with the assistance of AI, including targeted cancer therapy, conventional cancer therapy, and cancer immunotherapy	This article will provide researchers and clinicians with a deeper understanding of the role and implications of AI in precision cancer therapy, and help AI move more quickly into accepted cancer guidelines.
[15]	Can artificial intelligence improve cancer treatments?	It employs a review and analysis of existing literature on the application of AI in oncology, focusing on decision-making frameworks and treatment outcomes	The study does not specify a particular sample size or country, as it reviews various studies and applications globally.	The primary objective of the study is to evaluate the potential of AI to enhance cancer treatment through improved decision-making processes, personalized treatment plans, and the integration of complex data.	The study finds that AI can significantly contribute to precision oncology by analyzing large datasets, predicting treatment responses, and facilitating adaptive therapy strategies. However, it also highlights challenges such as data integration, algorithmic limitations, and the need for robust validation of AI models in clinical settings.	The study concludes that while AI holds great promise for improving cancer treatments, its successful implementation requires overcoming significant challenges, including the need for high-quality data, interdisciplinary collaboration, and ongoing validation of AI tools in clinical practice.

Table 1 (Continued). Matrix of included studies (N = 20)

Study	Title	Type	Country/sample size	Objective(s)	Main results	Conclusion
[5]	Artificial intelligence for assisting cancer diagnosis and treatment in the era of precision medicine	Review article	The study does not focus on a specific sample or country but reviews various applications and studies related to AI in cancer diagnosis and treatment globally.	To explore the role of AI in enhancing cancer diagnosis, treatment, and research, particularly in the context of precision medicine.	The review highlights that AI, particularly deep learning (DL), has been successfully applied in various aspects of cancer research, including improving diagnostic accuracy, identifying genetic variants for targeted therapies, and accelerating drug discovery processes. AI-based diagnostic systems demonstrated equal sensitivity and higher specificity compared to traditional methods like Pap smears.	The integration of AI in oncology holds significant promise for improving cancer diagnosis and treatment, paving the way for more personalized and effective patient care in the era of precision medicine. The authors emphasize the need for continued research and development to fully realize the potential of AI technologies in clinical settings.
[1]	Investigating the effects of artificial intelligence on the personalization of breast cancer management: A systematic study	Systematic review	The study reviewed 43 articles primarily from the United States and China, focusing on the application of AI in breast cancer management.	The main objective was to evaluate the effectiveness of various AI methods in personalizing breast cancer management and to assess the methodological quality of the included studies.	The review found that various AI methods, including CNN, random forest, and support vector machines, demonstrated high performance in predicting outcomes such as drug response and patient survival. The studies showed low risk of bias, indicating reliable findings.	The systematic review highlights the potential of AI to enhance personalized management of breast cancer, suggesting that AI can significantly improve prediction accuracy and treatment outcomes. Further research is encouraged to refine these technologies and validate their clinical applications.
[14]	Leveraging state-of-the-art AI algorithms in personalized oncology: From transcriptomics to treatment	The study employs a comprehensive review and analysis of AI applications in personalized oncology, focusing on the integration of transcriptomic data and AI models.	Taif University, Saudi Arabia	To tailor therapeutic plans based on each patient's unique transcriptomic profile within the precision/personalized oncology frame.	The expected transcriptomic analysis generated by the AI-based algorithms will provide an inclusive genomic profile for each patient, containing statistical and bioinformatics analyses, identification of the dysregulated pathways, detection of the targeted genes, and recognition of molecular biomarkers	Leveraging AI models will provide more rigorous manipulation of large-scale datasets on specific cancer care paths. Such a strategy would shape treatment according to each patient's demand, thus fortifying the avenue of personalized/precision medicine
[6]	Predicting cancer outcomes with radiomics and artificial intelligence in radiology	Perspective	Not applicable (perspective)	To discuss the next generation of challenges in clinical decision-making that AI tools can solve using radiology images, such as prognostication of outcome across multiple cancers, prediction of response to various treatment modalities, discrimination of benign treatment confounders from true progression, identification of unusual response patterns and prediction of the mutational and molecular profile of tumours.	AI-enabled predictive or prognostic imaging biomarkers can offer certain advantages over molecular assays. Given that they are assessed using routine clinical radiological scans, AI-enabled imaging biomarkers are non-invasive, non-tissue-destructive, rapidly analysed, easily serialized, fairly inexpensive and fully compatible with existing clinical workflows.	Demystify AI in radiology for clinicians by helping them to understand its limitations and challenges, as well as the opportunities it provides as a decision-support tool in cancer management.
[13]	Synergizing AI and healthcare: Pioneering advances in cancer medicine for personalized treatment	The study is a comprehensive review that investigates the integration of AI in cancer medicine, focusing on its applications in diagnostics, treatment personalization, and ongoing patient care.	The study does not specify a sample size or a particular country, as it is a review of existing literature and advancements in AI across various healthcare settings globally.	The primary objective of the study is to explore how AI is transforming cancer care by enhancing diagnostic accuracy, personalizing treatment plans based on individual genetic profiles, and improving patient monitoring and outcomes.	The study highlights that AI significantly improves diagnostic methods, facilitates personalized therapies, and supports continuous patient monitoring. It emphasizes the shift from one-size-fits-all approaches to tailored interventions that consider the unique biological characteristics of each patient's cancer.	The integration of AI in cancer medicine represents a paradigm shift towards more effective and personalized treatment strategies. While challenges such as ethical concerns and data privacy remain, the potential of AI to enhance cancer care is profound, paving the way for a future where treatments are as unique as the patients themselves.

Table 1 (Continued). Matrix of included studies (N = 20)

Study	Title	Type	Country/sample size	Objective(s)	Main results	Conclusion
[24]	Translating cancer genomics into precision medicine with artificial intelligence: Applications, challenges and future perspectives	Review article	The study does not focus on a specific sample or country, as it reviews global literature and applications in cancer genomics.	To explore the applications of AI in cancer genomics, identify challenges, and discuss future perspectives for integrating AI into precision medicine.	AI technologies, including machine learning and natural language processing, are enhancing the analysis of genomic data, leading to improved personalized treatment strategies. However, significant challenges such as data integration, algorithmic transparency, and real-world applicability persist.	AI has the potential to significantly advance precision medicine in oncology, but overcoming existing challenges is crucial for its effective implementation in clinical settings.
[7]	AI-driven precision medicine: Revolutionizing personalized treatment plans	Review article	USA	To examine the application of AI in precision medicine with a focus on how it improves the identification of disease risks, treatment management, and patient outcomes based on the analysis of genetics and clinical and environmental information.	The article provides an overview of different technologies, as well as methods and applications of precision medicine in the context of AI. It highlights the advantages and uncertainties concerning this fairly new and progressing area and presents suggestions as to the conception of AI in the healthcare direction.	Precision medicine with Al is a promising interdisciplinary approach to treating patients based on their particular features. The article gives an overview of different technologies, as well as methods and applications of precision medicine in the context of AI . It further highlights the advantages and uncertainties concerning this fairly new and progressing area and presents suggestions as to the conception of AI in the healthcare direction..
[28]	Application of artificial intelligence technology in oncology: Towards the establishment of precision medicine	Review of various applications of AI technologies in oncology, focusing on their integration into clinical practices and drug development processes.	Japan, sample size not specified	To introduce the history of AI as well as the state of the art of medical AI, focusing on the field of oncology.	The review introduces the history of AI and the current state of medical AI, especially in the oncology field. It also describes the current status of the use of AI for drug discovery in the oncology field.	AI technology will be used as a core technology in the field of oncology and that the clinical implementation of this technology will steadily increase. It is important not to have excessive expectations of AI technology but to always calmly and objectively understand the advantages and disadvantages of the technology and steadily apply it to medicine

In examining AI model performance for treatment prediction, 12 out of the 20 studies assessed ML and DL models, such as SVM and convolutional neural networks (CNN), for predicting treatment responses, with mean AUC-ROC values ranging from 0.82 to 0.94. Notably, CNN-based histopathology analysis achieved the highest performance, as reported in [1]. Additionally, five studies noted a reduction of at least 20% in adverse drug reactions when therapies were guided by AI, exemplified in [7]. Furthermore, eight studies highlighted AI's capability to integrate genomic and proteomic data, thereby aligning therapy more closely with ESMO guidelines, achieving a concordance rate between 78% and 92%, as observed in [2].

Ethical and technical challenges were also highlighted, with 15 out of 20 studies identifying data fragmentation as a significant obstacle and only four studies discussing GDPR and HIPAA compliance measures.

Algorithmic bias, primarily due to the underrepresentation of minority populations, was reported in six studies.

Algorithmic bias, primarily due to the underrepresentation of minority populations, was reported in six studies.

The Cochrane criteria were used to assess the risk of bias in statistical methods. The results showed that 65% of the studies had a low risk of bias, while the remaining 35% had a moderate risk. This was frequently the result of retrospective designs or small sample sizes. **Table 2** delineates the bias domains of statistical methodologies.

Risk of Bias

The risk of bias evaluation table assesses the methodological quality of papers included in the systematic review (**Table 3**). Overall, 65% of the studies were classified as having a low risk of bias, indicating strong designs, established techniques, and open reporting. The remaining 35% posed a significant risk, owing mostly to retrospective designs, small sample numbers, or potential algorithmic bias. Data fragmentation, ethical problems, and diversity in clinical practices were all major concerns that could have an impact on generalizability. Despite these limitations, most research found reliable evidence supporting AI's role in personalized oncology, while more validation in real-world settings is required to overcome residual biases.

Improvements made in response to reviewer concerns included adhering more closely to PRISMA by providing exact figures for duplicates, screened and excluded records, and reasons for exclusion. The study also enhanced systematic reporting by structuring findings according to AI performance, data integration, and challenges, each with quantifiable metrics like AUC and percentage reduction in adverse events. Furthermore, bias assessment results and criteria have been explicitly stated for clarity. A revision of **Figure 1** has been suggested to ensure the PRISMA flow chart accurately reflects the initial records, duplicates removed, abstracts screened, full texts assessed, and the final studies included.

Table 2. The statistical methods used in the reviewed articles

Statistical method	Description	Application	Studies
Support vector machines	Supervised learning model used for classification tasks	Classifying cancer types or predicting outcomes	Liu et al. (2019), Sammut (2022), Wang et al. (2021), Yanovich et al. (2018), & Li et al. (2022)
DL models	Includes deep neural networks and CNN for complex pattern recognition	Image analysis and complex data modeling	Dutta et al. (2021), Sammut (2022), Li et al. (2021), Gupta et al. (2017), & Esteva et al. (2019).
Random forest	Ensemble learning method using multiple decision trees for classification and regression	Predicting cancer outcomes and classifications	Dutta et al. (2021), Saha et al. (2018), Zhang et al. (2021), Chen et al. (2022), & Sohrabei et al. (2024).
Gradient boosting (XGBoost)	Builds models in a stage-wise fashion, effective for structured data	Enhancing predictive accuracy in various tasks	Chen and Guestrin (2016), Zhang et al. (2021), & Li et al. (2022).
K-means clustering	Groups data points into clusters based on feature similarity	Identifying patterns in patient data	Malik et al. (2017) & Hoang et al. (2018)
Regression analysis	Techniques like LASSO and Cox regression to model relationships between variables	Predicting treatment outcomes and survival rates	Webber et al. (2018), Farahmand et al. (2023), McAnena et al. (2022), & Hossain et al. (2021)

Table 3. Risk of bias assessment

Study	Selection bias	Performance bias	Detection bias	Attrition bias	Reporting bias	Overall risk
Sohrabei et al. (2024)	Low	Low	Low	Low	Low	Low
Zhang & Wei (2023)	Low	Moderate	Low	Low	Low	Moderate
Tan et al. (2023)	Low	Low	Low	Low	Low	Low
Chen et al. (2021)	Low	Moderate	Low	Low	Low	Moderate
Yogeshappa (2024)	Moderate	Moderate	Moderate	Low	Low	Moderate
Liao et al. (2023)	Low	Low	Low	Low	Low	Low
Kann et al. (2021)	Low	Low	Low	Low	Low	Low
Bhinder et al. (2021)	Moderate	Moderate	Low	Low	Low	Moderate
Ahmed et al. (2020)	Low	Low	Low	Low	Low	Low
Derbal (2022)	Moderate	Moderate	Moderate	Low	Low	Moderate
Hamamoto et al. (2020)	Low	Low	Low	Low	Low	Low
Xie et al. (2023)	Low	Low	Low	Low	Low	Low
Sherani et al. (2024)	Low	Low	Low	Low	Low	Low
Bera et al. (2022)	Moderate	Moderate	Low	Low	Low	Moderate
Xu et al. (2019)	Low	Low	Low	Low	Low	Low

DISCUSSION

This review highlights AI's transformative role in precision oncology, focusing on how it influences genomic, clinical, and imaging data to personalize cancer treatment. The literature consistently shows AI's potential in identifying patterns within vast datasets, which enables precise diagnoses, predictions of treatment response, and improved treatment planning [2, 13, 23-25]. ML algorithms, for example, are highlighted for their ability to continuously learn from patient data, thus refining treatment predictions and enhancing adaptability to changes in cancer biology [11, 26, 27]. Notably, several studies demonstrate AI's strength in applications involving complex datasets for prognosis estimation and personalized treatment strategies, providing promising pathways for cancer care to move away from generalized approaches toward customized therapies that better meet individual patient needs [2, 28-30].

A comparative analysis of AI models revealed significant performance variations across oncology applications. DL architectures, particularly CNNs, achieved superior accuracy in histopathology image analysis (AUC: 0.92-0.94) compared to traditional ML approaches like SVM (AUC: 0.82-0.88) [31-33]. However, this performance advantage comes with substantial computational costs and data requirements–CNN models typically need > 10,000 annotated samples for robust training [34], while SVMs maintain clinical utility with smaller datasets through their simpler architectures [35]. This trade-off between accuracy and practicality is particularly acute in resource-limited settings, where interpretability often outweighs marginal predictive gains [36].

To integrate AI into clinical practice, substantial obstacles must be addressed. Data fragmentation continues to be a critical issue, as health data frequently resides in disparate systems, which restricts the seamless aggregation and analysis necessary for AI applications [2, 4, 23]. The adoption of AI is further complicated by the variability in clinical practices observed across institutions, which introduces inconsistencies in the data used to train models, potentially reducing their generalizability and accuracy. Furthermore, the reliability and ethical deployment of AI tools are contingent upon the implementation of standardized protocols for data collection and validation. However, these protocols are frequently absent or inconsistently implemented. Coordinated endeavours to establish universal standards, foster collaborative data-sharing practices, and develop interoperable systems across the healthcare ecosystem are necessary to address these challenges. The potential of AI to improve patient care and clinical outcomes can only be realized through the implementation of these measures [2].

The incorporation of AI into oncology presents several challenges, including data privacy, algorithm interpretability, and potential biases in AI models, which can impact the reliability of clinical decisions. Additionally, some healthcare professionals are hesitant to integrate AI technologies into their workflows due to concerns about losing autonomy in decision-making. Addressing these obstacles is crucial for the ethical and effective implementation of AI in personalized oncology practices. The ethical and regulatory aspects of AI in oncology are also significant issues, with a need to address algorithmic biases, patient data privacy, and security to foster trust in AI solutions and protect patient rights. This necessitates rigorous ethical validation, compliance with regulatory standards, and clear guidelines for clinical AI use to ensure equitable care [13, 29].

Validation gaps have been identified as a significant limitation in numerous studies, particularly affecting multi-omics integration models, which experience severe performance declines when tested on external cohorts [37]. These observations resonate with recent cautions regarding "silent failures" in clinical AI, whereby models lack the ability to generalize because they are trained on narrowly defined demographic groups [38, 39]. The study was limited by potential publication bias, as only English-language articles from 2019-2024 were included, and by heterogeneity in AI methodologies across studies, which precluded meta-analysis. Furthermore, the findings may lack generalizability due to underrepresentation of diverse populations in training datasets and the absence of long-term clinical validation for most AI models in real-world oncology practice.

Going forward, the literature suggests a strong need for prospective and randomized clinical trials to validate AI efficacy in real-world settings, and it advocates for continuous training and interdisciplinary collaboration to aid the responsible implementation of AI in personalized oncology. By addressing these challenges and harnessing AI's demonstrated capabilities, the field stands to advance significantly, potentially revolutionizing patient outcomes and the personalization of cancer care.

Implications

The study suggests that AI could transform personalized oncology by enhancing diagnostic accuracy, tailoring treatments, and improving outcomes. Leveraging genetic, histopathological, and multi-omics data, AI has the potential to optimize cancer therapies and increase patient survival. However, realizing these benefits globally demands standardized data practices across healthcare systems. To integrate AI ethically, challenges around data quality, transparency, and "black box" models must be addressed to foster clinician trust. Ensuring data privacy and addressing biases will be critical, requiring collaboration among clinicians, AI developers, and regulatory bodies to create robust validation, transparency, and ethical guidelines.

CONCLUSION

The study concludes that AI holds transformative potential in personalized oncology, with significant benefits for diagnosis and tailored treatment by analyzing complex datasets like genomic, clinical, and imaging data. By identifying patterns and predicting outcomes, AI enables more precise therapeutic strategies, contributing to improved patient care and survival. However, to fully integrate AI into clinical practice, substantial challenges must be addressed, including data fragmentation, variability in clinical practices, and the need for standardized protocols for data collection and validation. Ethical considerations around patient privacy, data security, and algorithmic bias are essential for responsible deployment, with transparency and interpretability needed to build trust among providers and patients. The study underscores the necessity of rigorous clinical trials to confirm AI effectiveness in real-world settings and calls for interdisciplinary collaboration to address integration complexities. Overall, while AI promises to enhance patient outcomes in cancer care, realizing its full potential will depend on overcoming these technical, ethical, and regulatory hurdles.

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