Razavi J Med. In Press (...): e1408 doi: 10.30483/rjm.2025.254628.1408

Published online . **Systematic Review Article**

Challenges of Artificial Intelligence in Cancer Diagnosis: An Update on Future and Prospects

Bahare Rashidi[1], Kiarash Zohori[2], Seyyedeh Samin Aminzadeh[3], Seyedeh Fatemeh Abachi[4], Farnaz Behzad[5], Alireza Omranzadeh[6*]

1. Faculty of Pharmacy, Shiraz University of Medical Sciences, Shiraz, Iran
2. Pharmacy graduate, Faculty of Pharmacy, Ayatollah Amoli Branch, Islamic Azad University, Iran
3. Faculty of Pharmacy, Tabriz University of Medical Sciences, Tabriz, Iran
4. School of Medicine, Novosibirsk State University
5. Electrical Department, Faculty of Engineering, Islamic Azad University-South Tehran Branch, Tehran, Iran
6. Medical Doctor, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran

* ***Corresponding author:*** Alireza Omranzadeh; Medical Doctor, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran. Omranza921@mums.ac.ir

Received 2025 February 30**; Accepted** 2025 July 24.

Abstract

Background: Artificial intelligence (AI) has become increasingly prominent in the medical field, particularly in the diagnosis of cancer.

Objectives: This comprehensive review was conducted to review the challenges of AI in cancer diagnosis.

Methods: This comprehensive review was conducted through a systematic search of major scientific databases, including PubMed, Scopus, Web of Science, and IEEE Xplore, utilizing a combination of keywords and Medical Subject Headings (MeSH) terms such as "artificial intelligence," "machine learning," "deep learning," "neural networks," "cancer diagnosis," "oncological imaging," "pathology," "biomarkers," and "precision oncology," covering the period from January 2019 to December 2024 to capture the most relevant and impactful studies in this rapidly evolving field. The inclusion criteria were focused on peer-reviewed original research articles, significant review papers, and high-impact conference proceedings that demonstrated a direct application of AI algorithms in diagnostic procedures, while exclusion criteria encompassed non-English publications, studies with insufficient methodological detail, articles not focused on diagnostic applications, and editorials or opinion pieces without original data, ensuring a robust and evidence-based analysis of the current landscape.

Results: The challenges in the widespread utilization of this technology in clinical settings are discussed. Deep learning algorithms, especially convolutional neural networks (CNN), can identify suspicious areas in mammograms, CT scans, and MRI images that doctors may easily overlook. These capabilities improve accuracy and reduce human errors in cancer diagnosis. In addition to image analysis, AI can also analyze patients' molecular and genetic data. Using genomic and proteomic data, this technology can identify gene mutations and specific biological markers of cancer. As a result, early diagnosis and selection of targeted patient treatments are carried out with greater accuracy. However, despite significant progress in this field, several challenges remain, including the accurate interpretation of data, the need for substantial training data, and the ability to generalize algorithms to diverse populations.

Conclusion: In conclusion, AI is fundamentally augmenting the field of cancer diagnostics, moving from a theoretical promise to a powerful clinical tool. The evidence demonstrates that AI algorithms, particularly deep learning models, offer significant and measurable benefits.

Keywords: Artificial intelligence, Cancer diagnosis, Machine learning, Convolutional neural network, Medical image analysis

1. Background

Early detection of cancer can significantly increase the chances of successful treatment and save the patient's life (1). Artificial intelligence (AI) is revolutionizing the field of medicine by enhancing the accuracy and efficiency of medical care (2). It is widely used to analyze complex medical data, such as medical images from X-rays and MRIs, to assist in the early and precise detection of diseases like cancer. Furthermore, AI algorithms can help predict health risks, personalize treatment plans for individual patients, and accelerate the research and development of new drugs, ultimately leading to improved patient outcomes and a more advanced healthcare system (3).

New expectations have arisen as a result of the development of AI technology, which aims to enhance the precision and speed with which cancer can be diagnosed (4). However, despite the considerable promise of AI, several hurdles and constraints must be overcome before it can be integrated into clinical diagnostic systems. The most significant challenges to the widespread adoption of AI in cancer diagnosis, beyond the initial technical issues, necessitate deeper consideration and investigation (5). Access to high-quality, large, and diverse data from different centers, as the cornerstone for developing robust models, faces obstacles such as limited access, privacy issues, and data heterogeneity, which hinder the generalizability of algorithms (6-8). Serious issues, such as class imbalance, can have a significantly negative impact on model performance. Second, the “black box” nature of many deep learning algorithms, characterized by a lack of transparency in the inference of results, undermines clinical trust and makes their adoption difficult (9-11). However, the emergence of XAI or explainable AI technologies (such as SHAP and LIME techniques) has taken promising steps towards clarifying the output of models. Third, complex ethical and legal challenges, including patient data security, medical information ownership, and, in particular, the issue of determining legal liability in cases of AI-assisted misdiagnosis, remain unresolved (12, 13). Uneven digital infrastructure and the lack of standardized, interoperable systems in healthcare pose significant obstacles to the integration and effective deployment of these technologies in clinical settings.

The fact that AI relies on a massive quantity of clinical data is one of the most fundamental restrictions inherent to its use in the field of cancer detection (5). For AI algorithms to accurately detect complex cancer patterns, the data must be not only sufficiently varied but also reliable and properly categorized (14). In addition, changes in the quality of medical pictures, imaging techniques, and sample methodologies may all contribute to the risk of making an incorrect diagnosis (15). Given these concerns, it appears that the development of AI algorithms will encounter significant obstacles if professionals in radiology, pathology, and data science do not collaborate closely and effectively.

On the other hand, the issue of whether AI models can be interpreted has emerged as a significant concern for those working in the medical field. Numerous deep learning algorithms function like black boxes, meaning that even the developers of these models are unable to explain precisely how they arrived at a specific outcome (6). This lack of transparency may make it more difficult for patients and physicians to trust decisions made by AI. To overcome this issue, a substantial amount of research is being conducted to develop models that are both interpretable and explainable. This will enable medical professionals to utilize this technology with greater confidence when diagnosing and treating cancer.

Lastly, the ethical and legal concerns associated with the use of AI in cancer detection require careful consideration. Several concerns need to be addressed holistically, including patient privacy, ownership of medical data, and accountability for incorrect decisions (8). Additionally, concerns exist about the declining role of doctors in the diagnostic process and its impact on the relationship between doctors and patients (16). The creation of stringent standards and unambiguous norms, on the other hand, will enable us to look forward to a bright future in which AI and human professionals collaborate in the field of cancer detection. To address these issues, this review article aims to provide an analytical framework and propose viable solutions. Given the significant growth of AI applications in the field of oncology, this systematic review aims to summarize the existing evidence on AI applications in cancer diagnosis, analyze its clinical benefits, and especially deeply examine key challenges, including the generalizability of models, the black box problem, and implementation barriers in real clinical settings.

2. Objective

This comprehensive review was conducted to review the challenges of AI in cancer diagnosis.

3. Methods

The present evaluation involved the collection and analysis of data, providing a comprehensive examination of the challenges and opportunities associated with using AI to aid in cancer diagnosis. The first step was to search for terms related to AI, cancer diagnostics, machine learning, clinical issues, and ethical challenges in credible scientific databases, including PubMed, Scopus, Web of Science, and IEEE Xplore utilizing a combination of keywords and Medical Subject Headings (MeSH) terms such as “artificial intelligence,” “machine learning,” “deep learning,” “neural networks,” “cancer diagnosis,” “oncological imaging,” “pathology,” “biomarkers,” and “precision oncology,” covering the period from January 2019 to December 2024 to capture the most relevant and impactful studies in this rapidly evolving field. In addition, we reviewed pertinent papers, experimental studies, meta-analyses, and case reports to ensure comprehensive coverage of all aspects of the subject matter.

To ensure that the selected articles were of high quality and relevant to the topic, stringent selection criteria were employed. The titles and abstracts of all the publications discovered in the first stage were examined by two researchers who were not affiliated with each other. After that, they excluded any publications that were not pertinent to the subject of the study report. Following that, we performed a thorough reading of the complete texts of the other publications and selected only those that discussed the challenges that AI faced in the field of cancer detection, provided helpful solutions, or looked forward. In addition, measures were made to limit the influence of publication bias by incorporating studies that reported outcomes that were either negative or difficult.

To evaluate the quality of the selected studies, we used conventional appraisal instruments. In the case of empirical investigations, several factors were taken into consideration, including the sample size, research technique, internal and external validity, and the degree of accuracy of the findings. In the case of review articles and meta-analyses, we examined the number of sources that were used, the quality of the analysis performed on those sources, and the integrity of the findings. Last but not least, the information obtained from the selected studies was incorporated into an analytical framework to provide methodical answers to the research questions. To ensure the quality and relevance of all the data obtained, a stringent and multi-step approach was employed. This provided the review's findings with a solid basis. The current study selected 27 studies out of 246 studies published between 2020 and 2024 to ensure that contemporary research is represented.

4. Results

Early detection of cancer can significantly increase the chances of successful treatment and save the patient's life (17). Because in the early stages, tumors are small and confined and have not yet spread to other organs and tissues of the body (18). This enables more effective, less invasive treatments with fewer side effects, such as minor surgeries or targeted radiation therapy (19). As a result, patients not only have a higher chance of complete recovery, but their quality of life will also be much better during and after treatment (20). In fact, early detection is one of the key factors in reducing cancer mortality worldwide (21). Through the use of sophisticated machine learning algorithms and ideas, AI has completely transformed the process of diagnosing cancer (22). AI is capable of performing highly accurate analyses of medical images, including mammograms, CT scans, MRIs, and pathology images, among other types of medical imaging (23-25) (Figure 1).

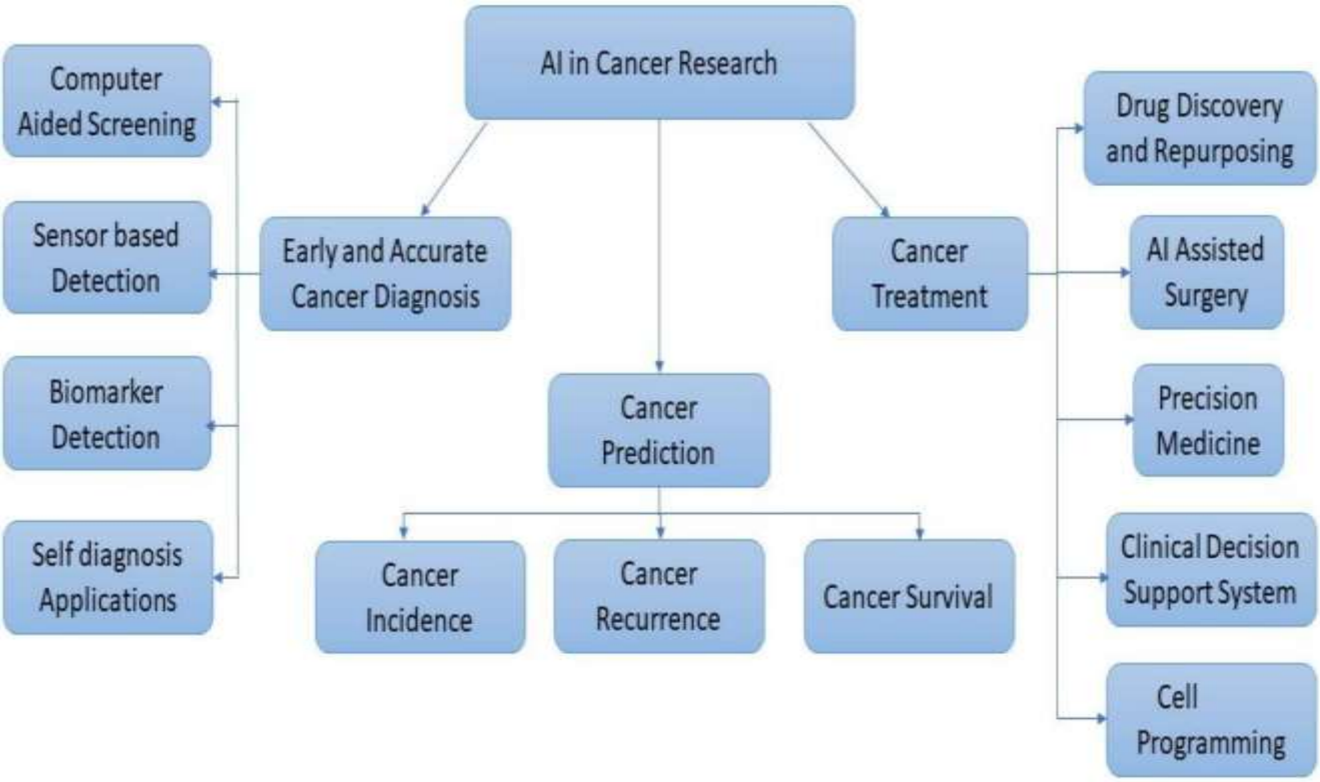

Figure 1. Approaches for cancer research using AI (26).

The diagnosis of cancer, particularly in its early stages, may be riddled with mistakes when using conventional approaches. However, AI has significantly improved the accuracy of diagnosis by spotting subtle patterns and microscopic alterations in tissues (27, 28). In the field of mammography, for instance, some AI models have the ability to identify and diagnose malignant lesions even when they are very tiny and low-density (29, 30). This skill is particularly noticeable in reducing the number of false positives and false negatives received (Figure 2).

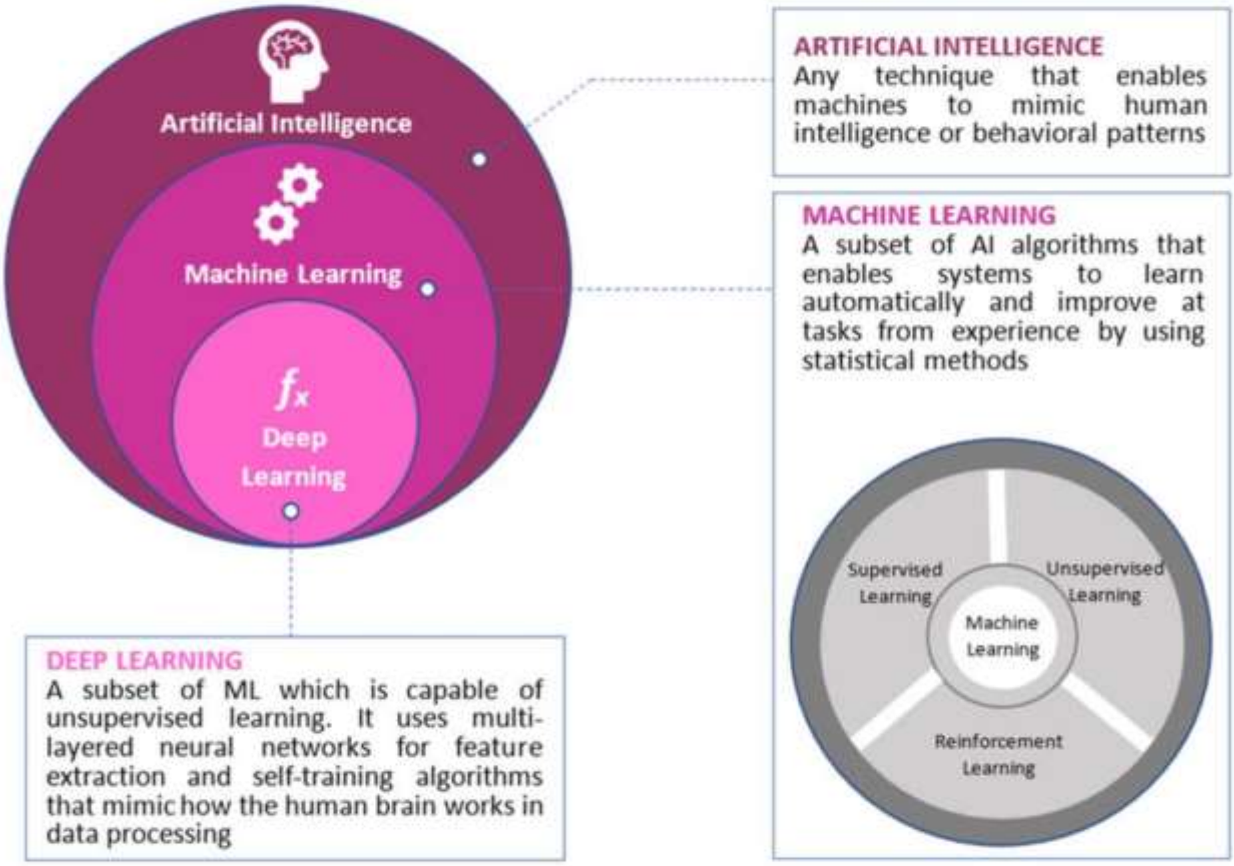

Figure 2. An overview of the differences between artificial intelligence (AI), machine learning (ML), and deep learning (DL) (31).

The analysis of pathology pictures is one of the most significant uses of AI in the field of cancer. Histology slides can be examined by AI-based systems with a high degree of speed and accuracy, and these systems can differentiate between normal and malignant cells (32, 33). When it comes to the diagnosis of prostate cancer, for instance, large-scale algorithms are able to distinguish between various tumor grades (Gleason Score) by analyzing biopsy samples with an accuracy that is comparable to or even superior to that of human pathologists. It has also been demonstrated that this method is effective in detecting the presence of lymph node metastases in various malignancies, including breast and colorectal cancer (34, 35). With the help of AI, the time required to analyze samples is drastically reduced, enabling a diagnosis to be made more quickly and with greater precision.

Also playing a significant role in the field of radiology is the application of AI. In CT scans and MRI images, advanced AI models can detect tiny cancers that traditional exams may overlook for various reasons (5, 36, 37). For example, AI systems can accurately identify nodules that are likely to be malignant, achieving a high level of detection in cases of lung cancer. These systems may also assess the features of the tumor microenvironment to predict the tumor's behavior. When it comes to 3D and dynamic imaging, AI is also used so that it can monitor changes over time and assist medical professionals in determining how well a patient is responding to therapy (15, 38).

Applications of AI can also be found in molecular and genomic studies, as well as in imaging. Individual patterns of gene expression, specific mutations, and biomarkers associated with cancer can be identified using sophisticated algorithms (39). Consequently, this enables medical professionals to differentiate between various subtypes and administer individualized therapies. Artificial intelligence can analyze data from next-generation sequencing (NGS) experiments to identify genetic changes that are predictive of cancer and assist in the selection of targeted treatments (40, 41). This is particularly helpful in situations when tumors are exhibiting resistance to the drugs being considered.

For cancer detection, AI technologies have also proved groundbreaking. Screening algorithms powered by AI can detect high-risk individuals with a high degree of precision and forecast the likelihood of developing cancer from the moment symptoms appear (18, 42, 43). Image processing techniques, for instance, have the ability to identify precancerous alterations in Pap smears with a high level of detection accuracy, hence reducing the need for further samples in the cervical cancer diagnosis process. By evaluating photos of skin lesions and directing patients to more specialist investigations, AI programs may also identify melanoma and other forms of skin cancer at an earlier stage (44-46).

Integrating data from multiple sources to enhance cancer detection is another important application of AI. Artificial intelligence systems can integrate imaging data, pathology, and a patient's clinical and genetic history to construct a comprehensive picture of the illness being presented. This is especially helpful in cases of complex tumors, such as glioblastoma or metastatic malignancies, where it can distinguish between various aspects of the tumor and assist medical professionals in making informed therapeutic decisions (Figure 3).

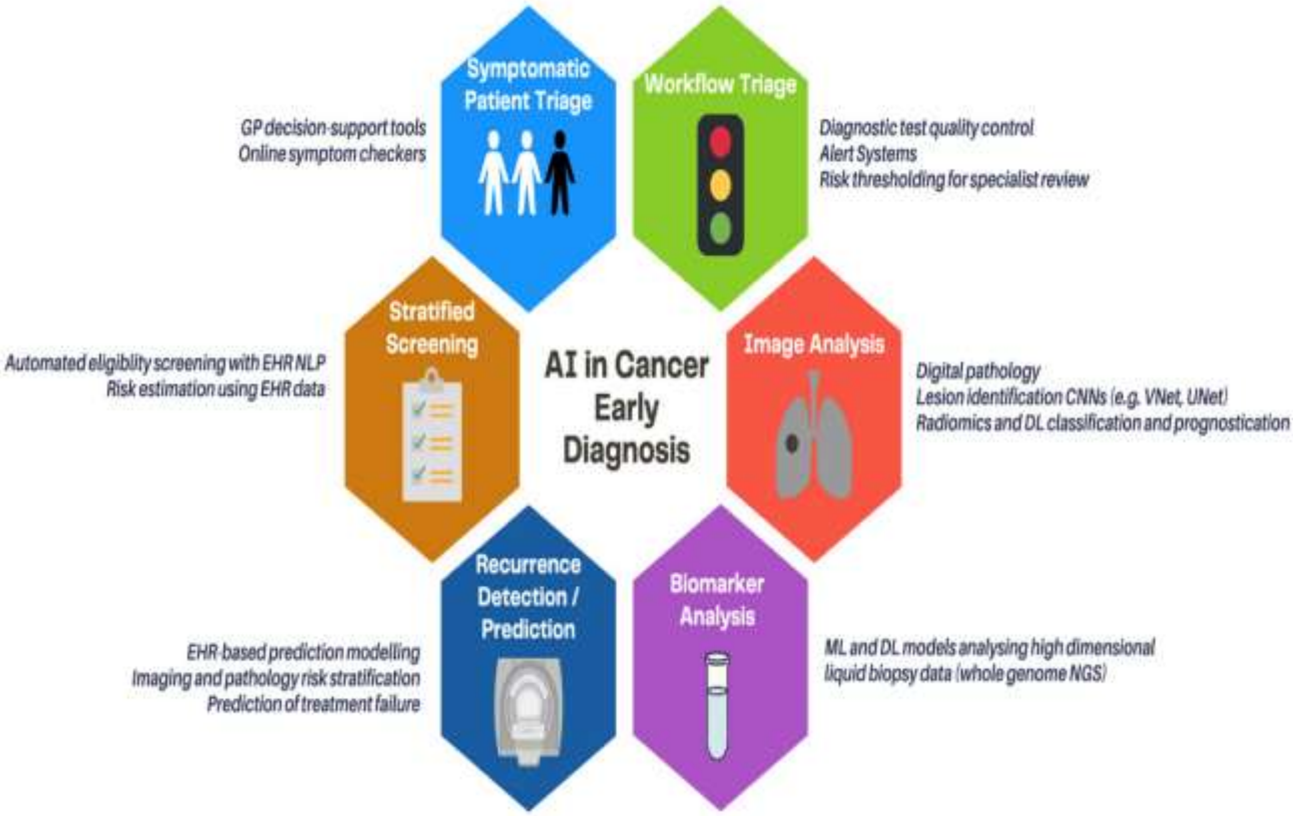

Figure 3. Clinical applications of AI in early cancer diagnosis. Abbreviations: GP: general practitioner, NLP: natural language processing, EHR: electronic healthcare record, ML: machine learning, DL: deep learning, NGS: next-generation sequencing (47).

5. Discussion

Despite its promise to transform cancer detection, AI faces a multitude of technological, clinical, and ethical challenges (48, 49). A significant conclusion that emerged from this investigation was that the accuracy of deep learning algorithms in identifying malignant lesions is greatly reliant on the quality and amount of training data (50, 51). Several studies highlight the fact that even the most powerful AI models experience a considerable decline in performance when they are trained on datasets that are either inadequate or imbalanced (including a small number of samples of uncommon cancer types) (52). This is particularly evident in cases of tumors with a low incidence but a high risk, where collecting adequate samples to train AI systems has become a significant challenge. On the other hand, an important aspect that decreases the generalizability of models and underscores the need for comprehensive standardization in this sector is the substantial variance in imaging techniques across various medical facilities (53, 54).

The inability to comprehend the results of deep learning models, sometimes referred to as the "black box problem," is one of the most significant problems of using AI in cancer diagnosis (55, 56). An analysis reveals that a significant number of robust AI systems are unable to offer clear explanations for how they arrive at their diagnosis. This is in contrast to the medical field, where it is essential to provide explicit reasons for diagnoses in order to win the confidence of both patients and doctors (57). Despite the high diagnostic accuracy of these systems, several studies have noted clinical resistance to their widespread adoption. This resistance is a result of the difficulty in explaining the decision-making process, which has led to higher diagnostic accuracy (58). In response to this obstacle, a new line of study has focused on the development of interpretable AI techniques, known as XAI (explainable AI). These approaches, although still in their early stages, show promise in addressing this fundamental problem (59).

Incorporating AI systems into standard cancer detection procedures is likely to encounter significant practical barriers (43, 60). Several AI algorithms perform remarkably well in controlled laboratory settings. However, when these algorithms are applied in real-world clinical settings, which are characterized by complexity and noise, their accuracy significantly decreases (26, 61, 62). It has also been noted as a key barrier to the clinical use of these technologies, as there is a dearth of integrated systems capable of automatically entering patient data into AI platforms and generating findings in a manner that is intelligible to physicians.

Findings concerning data privacy and liability issues were identified as concerning in the evaluation, which was conducted from an ethical and legal perspective of AI (63, 64). Since AI systems require a substantial amount of sensitive patient data to be trained, there are significant concerns regarding the protection of this information and the prevention of its exploitation (65). Even when anonymized data is linked with information from other sources, it is still possible to identify particular individuals, according to the findings of several studies that have issued warnings. On the other hand, the problem of assessing culpability in situations where AI systems make diagnostic errors has rapidly evolved into a complex legal task (66). Does the responsibility for liability reside with the individuals who developed the algorithm, with the practicing physician who used the results of the system, or with the medical institution that implemented the technology? It is necessary to establish new legal frameworks to address these unresolved problems.

Despite these obstacles, there are

potential advancements in several domains. When it comes to the technological side of things, the introduction of new neural network designs that need less training data (such as transfer learning and multitask learning) has shown promise in removing some of the hurdles (67). In addition, the issue of a shortage of varied and high-quality data is being progressively addressed by the construction of large, multi-center data banks. These databases are being developed in collaboration with a variety of research institutes worldwide (68). In some of the studies examined, AI systems trained on these datasets displayed performance comparable to or even better than that of human specialists in diagnosing certain forms of cancer (69). On the other hand, these findings require verification through more extensive research.

Use of AI in health systems necessitates significant alterations to the digital infrastructure. This is true from both an organizational and operational perspective. There is a lack of integrated and standardized information systems in many healthcare settings (47). These systems are unable to gather the data that AI requires in a consistent and processable manner. When discrepancies in medical record standards and patient demographics across countries are taken into consideration, this situation becomes significantly more complicated (22). The full promise of AI in cancer detection will not be achieved, according to studies, until significant investments are made in digital health infrastructure and standardized frameworks for data interchange are established (70).

There are noteworthy paradoxes, particularly concerning social acceptability and public trust. Generally speaking, patients have a favorable attitude toward the use of AI in cancer detection, particularly if it results in an earlier and more accurate diagnosis. This is the case, according to surveys. The same patients, on the other hand, are less likely to fully eliminate the function of human physicians in the diagnosis process. Instead, they would rather see AI as an auxiliary tool that can be used in conjunction with experts. The significance of this discovery lies in the fact that it highlights the necessity of establishing collaborative models that incorporate both human and AI capabilities, where each complements the other, and the physician's clinical judgment is used to guide the final choice.

This analysis also highlights the economic challenges associated with the use of AI systems in cancer detection, which is another important aspect that was uncovered. There is a high initial cost associated with creating, installing, and maintaining AI systems; however, this technology has the potential to yield significant long-term savings. As a result, there is a significant obstacle to overcome, particularly for smaller healthcare institutions and nations with lower incomes. According to studies, public-private partnership models and cloud-based shared systems have the potential to be effective solutions for reducing this financial burden. However, for these models to be successfully implemented, rigorous coordination and regulation are necessary (Table 1).

Table 1. This table provides a structured overview of how AI is currently used in cancer diagnosis, the obstacles it faces, and potential advancements on the horizon

Category	Applications	Challenges	Future Directions	Reference
Medical Imaging	Tumor detection in X-rays, CT, MRI, and mammography	Requires large, diverse datasets for training	Integration with real-time imaging systems	(15, 71,72)
	Early detection of lung nodules, breast lesions, and brain tumors	Limited generalizability across different populations	Development of portable AI imaging tools	
	Automated segmentation of tumors	High false-positive rates in some cases	AI-powered 3D tumor modeling for surgery	
Pathology	Digital pathology for analyzing biopsy samples	Difficulty in interpreting rare cancer types	AI-assisted robotic pathology labs	(34, 73-75)
	Grading tumors (e.g., Gleason score for prostate cancer)	High computational power needed for high-resolution images	Cloud-based pathology networks for global collaboration	
	Identifying metastatic cells in lymph nodes	Ethical concerns over misdiagnosis	AI for predicting tumor aggressiveness from histology	
Genomics	Identifying cancer-driving mutations	High cost of genomic sequencing	Personalized treatment based on AI-predicted mutations	(76, 77)
	Predicting drug resistance	Complex data integration (multi-omics)	AI-guided CRISPR and gene therapy for cancer	
	Subtyping cancers based on molecular profiles	Limited clinical validation of AI models	Real-time genomic monitoring of tumors	
Early Detection	AI-powered screening for high-risk patients	Privacy concerns with patient data	Wearable AI devices for continuous cancer monitoring	(78, 79)
	Liquid biopsy analysis for circulating tumor DNA	Regulatory hurdles in clinical adoption	Non-invasive AI-based cancer blood tests	
	Predictive models for cancer predisposition	Bias in training data affecting accuracy	Population-wide AI screening programs	
Treatment Planning	Optimizing radiation therapy targeting	Lack of interpretability in deep learning models	AI-driven adaptive radiotherapy	(80-84)
	Predicting immunotherapy response	Integration with existing hospital systems	AI for dynamic treatment adjustments	
	Personalized chemotherapy recommendations	Limited real-world validation	Closed-loop AI treatment systems	
Prognosis	Survival prediction models	Ethical issues in end-of-life predictions	AI for long-term cancer recurrence monitoring	(85-87)
	Risk stratification for recurrence	Patient anxiety from AI-based predictions	Integration with electronic health records (EHRs)	
	Monitoring treatment response in real-time	Lack of standardized benchmarks	AI-powered patient outcome dashboards	
Operational	Reducing radiologist workload through automation	Job displacement concerns	AI-assisted telemedicine for cancer diagnosis	(88, 89)
	Prioritizing urgent cases in diagnostic workflows	Liability and malpractice risks	Federated learning for global AI model training	
	Cost reduction in cancer screening programs	High initial infrastructure costs	Blockchain for secure AI data sharing	

6. Conclusion

Ultimately, the findings of this review underscore the pressing need for interdisciplinary research in this field. Solving the challenges of AI in cancer diagnosis requires close collaboration between computer scientists, clinicians, ethicists, lawyers, and policymakers. The successful studies reviewed in this review all shared a commonality: multidisciplinary research teams that were able to examine the issues from multiple angles. This integrated approach is essential not only for technological advancements but also for designing systems that are clinically useful, ethically defensible, and legally robust. A forward-looking analysis of the findings of this review suggests that, despite all the challenges, AI will gradually establish itself in cancer diagnosis systems. However, this process will be gradual, and it will likely take decades to transform the field entirely. It is predicted that shortly, AI systems will first appear as diagnostic assistants that reduce human errors, and gradually, as trust increases. The future path is to develop explainable AI models based on comprehensive and multi-center data that are integrated into the health system, not only as a diagnostic tool, but also as a transparent and reliable assistant for doctors, within an ethical framework and with integrated infrastructure.

Acknowledgements: Not applicable.

Availability of data and materials: The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of interests: The authors declare no conflict of interest.

Consent for publication: Not applicable.

Ethics approval and consent to participate: The present study was conducted in terms of the principles of the revised Declaration of Helsinki, which is a statement of ethical principles that directs physicians and other participants in medical research involving human subjects.

Financial disclosure: No funding was received to conduct this study.

Author contributions: Conceptualization: [Alireza Omeanzadeh], Methodology: [All authors]; Formal analysis and investigation: [All authors]; Writing-original draft preparation: [All authors]; Writing - review and editing: [All Authors]; Funding acquisition: [Self-funding]; Supervision: [Alireza Omeanzadeh]. All authors checked and approved the final version of the manuscript for publication in the present journal.

References

1. Hajjafari A, Sadr S, Rahdar A, Bayat M, Lotfalizadeh N, Dianaty S, et al. Exploring the integration of nanotechnology in the development and application of biosensors for enhanced detection and monitoring of colorectal cancer. Inorganic Chemistry Communications. 2024;164:112409. https://doi.org/10.1016/j.inoche.2024.112409
2. Faiyazuddin M, Rahman SJQ, Anand G, Siddiqui RK, Mehta R, Khatib MN, et al. The impact of artificial intelligence on healthcare: a comprehensive review of advancements in diagnostics, treatment, and operational efficiency. Health Science Reports. 2025;8(1):e70312. https://doi.org/10.1002/hsr2.70312PMid:39763580 PMCid:PMC11702416
3. Alowais SA, Alghamdi SS, Alsuhebany N, Alqahtani T, Alshaya AI, Almohareb SN, et al. Revolutionizing healthcare: the role of artificial intelligence in clinical practice. BMC medical education. 2023;23(1):689. https://doi.org/10.1186/s12909-023-04698-zPMid:37740191 PMCid:PMC10517477
4. Chen ZH, Lin L, Wu CF, Li CF, Xu RH, Sun Y. Artificial intelligence for assisting cancer diagnosis and treatment in the era of precision medicine. Cancer Communications. 2021;41(11):1100-15. https://doi.org/10.1002/cac2.12215PMid:34613667 PMCid:PMC8626610
5. Bi WL, Hosny A, Schabath MB, Giger ML, Birkbak NJ, Mehrtash A, et al. Artificial intelligence in cancer imaging: clinical challenges and applications. CA: a cancer journal for clinicians. 2019;69(2):127-57. https://doi.org/10.3322/caac.21552 PMid:30720861 PMCid:PMC6403009
6. Ahmad Z, Rahim S, Zubair M, Abdul-Ghafar J. Artificial intelligence (AI) in medicine, current applications and future role with special emphasis on its potential and promise in pathology: present and future impact, obstacles including costs and acceptance among pathologists, practical and philosophical considerations. A comprehensive review. Diagnostic pathology. 2021;16(1):24. https://doi.org/10.1186/s13000-021-01085-4 PMid:33731170 PMCid:PMC7971952
7. Dixit S, Kumar A, Srinivasan K. A current review of machine learning and deep learning models in oral cancer diagnosis: recent technologies, open challenges, and

future research directions. Diagnostics. 2023;13(7):1353. https://doi.org/10.3390/diagnostics13071353 PMid:37046571 PMCid:PMC10093759
8. Carter SM, Rogers W, Win KT, Frazer H, Richards B, Houssami N. The ethical, legal and social implications of using artificial intelligence systems in breast cancer care. The Breast. 2020;49:25-32. https://doi.org/10.1016/j.breast.2019.10.001PMid:31677530 PMCid:PMC7375671
9. Marey A, Arjmand P, Alerab ADS, Eslami MJ, Saad AM, Sanchez N, et al. Explainability, transparency and black box challenges of AI in radiology: impact on patient care in cardiovascular radiology. Egyptian Journal of Radiology and Nuclear Medicine. 2024;55(1):183. https://doi.org/10.1186/s43055-024-01356-2
10. Sendak M, Elish MC, Gao M, Futoma J, Ratliff W, Nichols M, et al., editors. " The human body is a black box" supporting clinical decision-making with deep learning. Proceedings of the 2020 conference on fairness, accountability, and transparency; 2020. https://doi.org/10.1145/3351095.3372827
11. Murad NY, Hasan MH, Azam MH, Yousuf N, Yalli JS. Unraveling the black box: A review of explainable deep learning healthcare techniques. IEEE Access. 2024;12:66556-68. https://doi.org/10.1109/ACCESS.2024.3398203
12. Nogaroli R. Ethical and Legal Aspects of Artificial Intelligence (AI) in Medical Service Contracts. Medical Liability and Artificial Intelligence: Brazilian and European Legal Approaches: Springer; 2025. p. 123-206. https://doi.org/10.1007/978-3-031-94306-5_4
13. Rashid M, Sharma M. AI-Assisted Diagnosis and Treatment Planning-A Discussion of How AI Can Assist Healthcare Professionals in Making More Accurate Diagnoses and Treatment Plans for Diseases. AI in Disease Detection: Advancements and Applications. 2025:313-36. https://doi.org/10.1002/9781394278695.ch14
14. Elemento O, Leslie C, Lundin J, Tourassi G. Artificial intelligence in cancer research, diagnosis and therapy. Nature Reviews Cancer. 2021;21(12):747-52. https://doi.org/10.1038/s41568-021-00399-1 PMid:34535775
15. Oyeniyi J, Oluwaseyi P. Emerging trends in AI-powered medical imaging: enhancing diagnostic accuracy and treatment decisions. International Journal of Enhanced Research In Science Technology & Engineering. 2024;13(4):81-94.
16. Durur-Subasi I, Özçelik ŞB. Artificial Intelligence in breast imaging: opportunities, challenges, and legal-ethical considerations. The Eurasian Journal of Medicine. 2023;55(Suppl 1):S114. https://doi.org/10.5152/eurasianjmed.2023.23360 PMid:39128072 PMCid:PMC11075018
17. Sadr S, Hajjafari A, Rahdar A, Pandey S, Jafroodi PP, Lotfalizadeh N, et al. Gold nanobiosensors and Machine Learning: Pioneering breakthroughs in precision breast cancer detection. European Journal of Medicinal Chemistry Reports. 2024;12:100238. https://doi.org/10.1016/j.ejmcr.2024.100238
18. Fitzgerald RC, Antoniou AC, Fruk L, Rosenfeld N. The future of early cancer detection. Nature medicine. 2022;28(4):666-77. https://doi.org/10.1038/s41591-022-01746-x PMid:35440720
19. Schiffman JD, Fisher PG, Gibbs P. Early detection of cancer: past, present, and future. American Society of Clinical Oncology Educational Book. 2015;35(1):57-65. https://doi.org/10.14694/EdBook_AM.2015.35.57 PMid:25993143
20. Crosby D, Bhatia S, Brindle KM, Coussens LM, Dive C, Emberton M, et al. Early detection of cancer. Science. 2022;375(6586):eaay9040. https://doi.org/10.1126/science.aay9040 PMid:35298272
21. Sadr S, Rahdar A, Pandey S, Hajjafari A, Soroushianfar M, Sepahvand H, et al. Revolutionizing cancer detection: harnessing quantum dots and graphene-based nanobiosensors for lung and breast cancer diagnosis. BioNanoScience. 2025;15(1):111. https://doi.org/10.1007/s12668-024-01639-y
22. Iqbal MJ, Javed Z, Sadia H, Qureshi IA, Irshad A, Ahmed R, et al. Clinical applications of artificial intelligence and machine learning in cancer diagnosis: looking into the future. Cancer cell international. 2021;21(1):270. https://doi.org/10.1186/s12935-021-01981-1 PMid:34020642 PMCid:PMC8139146

23. Khalifa M, Albadawy M. AI in diagnostic imaging: revolutionising accuracy and efficiency. Computer Methods and programs in biomedicine update. 2024;5:100146. https://doi.org/10.1016/j.cmpbup.2024.100146
24. Panayides AS, Amini A, Filipovic ND, Sharma A, Tsaftaris SA, Young A, et al. AI in medical imaging informatics: current challenges and future directions. IEEE journal of biomedical and health informatics. 2020;24(7):1837-57. https://doi.org/10.1109/JBHI.2020.2991043 PMid:32609615 PMCid:PMC8580417
25. Obuchowicz R, Strzelecki M, Piórkowski A. Clinical applications of artificial intelligence in medical imaging and image processing-A review. MDPI; 2024. p. 1870. https://doi.org/10.3390/books978-3-7258-1260-8
26. Sebastian AM, Peter D. Artificial intelligence in cancer research: trends, challenges and future directions. Life. 2022;12(12):1991. https://doi.org/10.3390/life12121991 PMid:36556356 PMCid:PMC9786074
27. Acs B, Rantalainen M, Hartman J. Artificial intelligence as the next step towards precision pathology. Journal of internal medicine. 2020;288(1):62-81. https://doi.org/10.1111/joim.13030 PMid:32128929
28. Shafi S, Parwani AV. Artificial intelligence in diagnostic pathology. Diagnostic pathology. 2023;18(1):109. https://doi.org/10.1186/s13000-023-01375-z PMid:37784122 PMCid:PMC10546747
29. Carriero A, Groenhoff L, Vologina E, Basile P, Albera M. Deep learning in breast cancer imaging: State of the art and recent advancements in early 2024. Diagnostics. 2024;14(8):848. https://doi.org/10.3390/diagnostics14080848PMid:38667493 PMCid:PMC11048882
30. Taib AG, Partridge GJW, Yao L, Darker I, Chen Y. The evaluation of artificial intelligence in mammography-based breast cancer screening: Is breast-level analysis enough? European Radiology. 2025:1-14. https://doi.org/10.1007/s00330-025-11733-8 PMid:40563050
31. Mitsala A, Tsalikidis C, Pitiakoudis M, Simopoulos C, Tsaroucha AK. Artificial intelligence in colorectal cancer screening, diagnosis and treatment. A new era. Current Oncology. 2021;28(3):1581-607. https://doi.org/10.3390/curroncol28030149 PMid:33922402 PMCid:PMC8161764
32. Wang K-S, Yu G, Xu C, Meng X-H, Zhou J, Zheng C, et al. Accurate diagnosis of colorectal cancer based on histopathology images using artificial intelligence. BMC medicine. 2021;19(1):76. https://doi.org/10.1186/s12916-021-01942-5 PMid:33752648 PMCid:PMC7986569
33. McCaffrey C, Jahangir C, Murphy C, Burke C, Gallagher WM, Rahman A. Artificial intelligence in digital histopathology for predicting patient prognosis and treatment efficacy in breast cancer. Expert review of molecular diagnostics. 2024;24(5):363-77. https://doi.org/10.1080/14737159.2024.2346545 PMid:38655907
34. Soliman A, Li Z, Parwani AV. Artificial intelligence's impact on breast cancer pathology: a literature review. Diagnostic pathology. 2024;19(1):38. https://doi.org/10.1186/s13000-024-01453-w PMid:38388367 PMCid:PMC10882736
35. Faa G, Coghe F, Pretta A, Castagnola M, Van Eyken P, Saba L, et al. Artificial intelligence models for the detection of microsatellite instability from whole-slide imaging of colorectal cancer. Diagnostics. 2024;14(15):1605. https://doi.org/10.3390/diagnostics14151605 PMid:39125481 PMCid:PMC11311951
36. Agarwal S, Yadav AS, Dinesh V, Vatsav KSS, Prakash KSS, Jaiswal S. By artificial intelligence algorithms and machine learning models to diagnosis cancer. Materials Today: Proceedings. 2023;80:2969-75. https://doi.org/10.1016/j.matpr.2021.07.088
37. Silva HECd, Santos GNM, Leite AF, Mesquita CRM, Figueiredo PTdS, Stefani CM, et al. The use of artificial intelligence tools in cancer detection compared to the traditional diagnostic imaging methods: An overview of the systematic reviews. Plos one. 2023;18(10):e0292063. https://doi.org/10.1371/journal.pone.0292063 PMid:37796946 PMCid:PMC10553229
38. Pinto-Coelho L. How artificial intelligence is shaping medical imaging technology: a survey of innovations and applications.

Bioengineering. 2023;10(12):1435. https://doi.org/10.3390/bioengineering10121435 PMid:38136026 PMCid:PMC10740686
39. Martinez-Ledesma E, Verhaak RG, Treviño V. Identification of a multi-cancer gene expression biomarker for cancer clinical outcomes using a network-based algorithm. Scientific reports. 2015;5(1):11966. https://doi.org/10.1038/srep11966 PMid:26202601 PMCid:PMC5378879
40. Park Y, Heider D, Hauschild A-C. Integrative analysis of next-generation sequencing for next-generation cancer research toward artificial intelligence. Cancers. 2021;13(13):3148. https://doi.org/10.3390/cancers13133148 PMid:34202427 PMCid:PMC8269018
41. Quazi S. Artificial intelligence and machine learning in precision and genomic medicine. Medical Oncology. 2022;39(8):120. https://doi.org/10.1007/s12032-022-01711-1 PMid:35704152 PMCid:PMC9198206
42. Thaker NG, Dicker AP, Loaiza-Bonilla A, Wallace A, Kolman D, Godshalk Ruggles A, et al. The role of artificial intelligence in early cancer detection: Exploring early clinical applications. AI in Precision Oncology. 2024;1(2):91-105. https://doi.org/10.1089/aipo.2024.0003
43. Tiwari A, Mishra S, Kuo T-R. Current AI technologies in cancer diagnostics and treatment. Molecular Cancer. 2025;24(1):159. https://doi.org/10.1186/s12943-025-02369-9 PMid:40457408 PMCid:PMC12128506
44. Phillips M, Marsden H, Jaffe W, Matin RN, Wali GN, Greenhalgh J, et al. Assessment of accuracy of an artificial intelligence algorithm to detect melanoma in images of skin lesions. JAMA network open. 2019;2(10):e1913436. https://doi.org/10.1001/jamanetworkopen.2019.13436 PMid:31617929 PMCid:PMC6806667
45. Jones O, Matin R, Van der Schaar M, Bhayankaram KP, Ranmuthu C, Islam M, et al. Artificial intelligence and machine learning algorithms for early detection of skin cancer in community and primary care settings: a systematic review. The Lancet Digital Health. 2022;4(6):e466-e76. https://doi.org/10.1016/S2589-7500(22)00023-1 PMid:35623799
46. Patel RH, Foltz EA, Witkowski A, Ludzik J. Analysis of artificial intelligence-based approaches applied to non-invasive imaging for early detection of melanoma: a systematic review. Cancers. 2023;15(19):4694.https://doi.org/10.3390/cancers15194694 PMid:37835388 PMCid:PMC10571810
47. Hunter B, Hindocha S, Lee RW. The role of artificial intelligence in early cancer diagnosis. Cancers. 2022;14(6):1524.https://doi.org/10.3390/cancers14061524PMid:35326674 PMCid:PMC8946688
48. Naseri H, Safaei AA. Diagnosis and prognosis of melanoma from dermoscopy images using machine learning and deep learning: a systematic literature review. BMC cancer. 2025;25(1):75. https://doi.org/10.1186/s12885-024-13423-yPMid:39806282 PMCid:PMC11727731
49. Tran KA, Kondrashova O, Bradley A, Williams ED, Pearson JV, Waddell N. Deep learning in cancer diagnosis, prognosis and treatment selection. Genome medicine. 2021;13(1):152. https://doi.org/10.1186/s13073-021-00968-x PMid:34579788 PMCid:PMC8477474
50. Hussain D, Al-Masni MA, Aslam M, Sadeghi-Niaraki A, Hussain J, Gu YH, et al. Revolutionizing tumor detection and classification in multimodality imaging based on deep learning approaches: Methods, applications and limitations. Journal of X-Ray Science and Technology. 2024;32(4):857-911. https://doi.org/10.3233/XST-230429 PMid:38701131
51. Azer SA. Deep learning with convolutional neural networks for identification of liver masses and hepatocellular carcinoma: A systematic review. World journal of gastrointestinal oncology. 2019;11(12):1218. https://doi.org/10.4251/wjgo.v11.i12.1218 PMid:31908726 PMCid:PMC6937442
52. Jiang X, Hu Z, Wang S, Zhang Y. Deep learning for medical image-based cancer diagnosis. Cancers. 2023;15(14):3608. https://doi.org/10.3390/cancers15143608 PMid:37509272 PMCid:PMC10377683

53. Kumar RR, Priyadarshi R. Denoising and segmentation in medical image analysis: A comprehensive review on machine learning and deep learning approaches. Multimedia Tools and Applications. 2024:1-59. https://doi.org/10.1007/s11042-024-19313-6
54. Li X, Zhang L, Yang J, Teng F. Role of artificial intelligence in medical image analysis: A review of current trends and future directions. Journal of Medical and Biological Engineering. 2024;44(2):231-43. https://doi.org/10.1007/s40846-024-00863-x
55. ŞAHiN E, Arslan NN, Özdemir D. Unlocking the black box: an in-depth review on interpretability, explainability, and reliability in deep learning. Neural Computing and Applications. 2025;37(2):859-965. https://doi.org/10.1007/s00521-024-10437-2
56. Hassija V, Chamola V, Mahapatra A, Singal A, Goel D, Huang K, et al. Interpreting black-box models: a review on explainable artificial intelligence. Cognitive Computation. 2024;16(1):45-74. https://doi.org/10.1007/s12559-023-10179-8
57. Das A, Rad P. Opportunities and challenges in explainable artificial intelligence (xai): A survey. arXiv preprint arXiv:200611371. 2020.
58. Rawal A, McCoy J, Rawat DB, Sadler BM, Amant RS. Recent advances in trustworthy explainable artificial intelligence: Status, challenges, and perspectives. IEEE Transactions on Artificial Intelligence. 2021;3(6):852-66. https://doi.org/10.1109/TAI.2021.3133846
59. dadi A, Berrada M. Peeking inside the black-box: a survey on explainable artificial intelligence (XAI). IEEE access. 2018;6:52138-60. https://doi.org/10.1109/ACCESS.2018.2870052
60. Huang D, Li Z, Jiang T, Yang C, Li N. Artificial intelligence in lung cancer: current applications, future perspectives, and challenges. Frontiers in Oncology. 2024;14:1486310. https://doi.org/10.3389/fonc.2024.1486310 PMid:39763611 PMCid:PMC11700796
61. Sandbank J, Bataillon G, Nudelman A, Krasnitsky I, Mikulinsky R, Bien L, et al. Validation and real-world clinical application of an artificial intelligence algorithm for breast cancer detection in biopsies. NPJ breast cancer. 2022;8(1):129. https://doi.org/10.1038/s41523-022-00496-w PMid:36473870 PMCid:PMC9723672
62. Zhang B, Shi H, Wang H. Machine learning and AI in cancer prognosis, prediction, and treatment selection: a critical approach. Journal of multidisciplinary healthcare. 2023:1779-91. https://doi.org/10.2147/JMDH.S410301PMid:37398894 PMCid:PMC10312208
63. Sumartono E, Harliyanto R, Situmeang SMT, Siagian DS, Septaria E. The legal implications of data privacy laws, cybersecurity regulations, and ai ethics in a digital society. The Journal of Academic Science. 2024;1(2):103-10. https://doi.org/10.59613/29qypw51
64. Stahl BC, Wright D. Ethics and privacy in AI and big data: Implementing responsible research and innovation. IEEE Security & Privacy. 2018;16(3):26-33. https://doi.org/10.1109/MSP.2018.2701164
65. Dlamini Z, Francies FZ, Hull R, Marima R. Artificial intelligence (AI) and big data in cancer and precision oncology. Computational and structural biotechnology journal. 2020;18:2300-11. https://doi.org/10.1016/j.csbj.2020.08.019 PMid:32994889 PMCid:PMC7490765
66. Williamson SM, Prybutok V. Balancing privacy and progress: a review of privacy challenges, systemic oversight, and patient perceptions in AI-driven healthcare. Applied Sciences. 2024;14(2):675. https://doi.org/10.3390/app14020675
67. Shen J, Zhang CJ, Jiang B, Chen J, Song J, Liu Z, et al. Artificial intelligence versus clinicians in disease diagnosis: systematic review. JMIR medical informatics. 2019;7(3):e10010. https://doi.org/10.2196/10010 PMid:31420959 PMCid:PMC6716335
68. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nature medicine. 2019;25(1):44-56. https://doi.org/10.1038/s41591-018-0300-7 PMid:30617339
69. Liu X, Faes L, Kale AU, Wagner SK, Fu DJ, Bruynseels A, et al. A comparison of deep learning performance against health-care professionals in detecting diseases from

medical imaging: a systematic review and meta-analysis. The lancet digital health. 2019;1(6):e271-e97. https://doi.org/10.1016/S2589-7500(19)30123-2 PMid:33323251
70. Kourou K, Exarchos KP, Papaloukas C, Sakaloglou P, Exarchos T, Fotiadis DI. Applied machine learning in cancer research: A systematic review for patient diagnosis, classification and prognosis. Computational and structural biotechnology journal. 2021;19:5546-55. https://doi.org/10.1016/j.csbj.2021.10.006 PMid:34712399 PMCid:PMC8523813
71. Pallumeera M, Giang JC, Singh R, Pracha NS, Makary MS. Evolving and Novel Applications of Artificial Intelligence in Cancer Imaging. Cancers. 2025;17(9):1510. https://doi.org/10.3390/cancers17091510 PMid:40361437 PMCid:PMC12070983
72. Shahid MS, Imran A. Breast cancer detection using deep learning techniques: challenges and future directions. Multimedia Tools and Applications. 2025;84(6):3257-304. https://doi.org/10.1007/s11042-025-20606-7
73. Rigby E, Vidya R, Shaaban AM. Use of digital pathology and artificial intelligence (AI) in breast cancer diagnosis and management: Opportunities and challenges. Diagnostic Histopathology. 2025. https://doi.org/10.1016/j.mpdhp.2024.12.005
74. Zhang DY, Venkat A, Khasawneh H, Sali R, Zhang V, Pei Z. Implementation of digital pathology and artificial intelligence in routine pathology practice. Laboratory Investigation. 2024;104(9):102111. https://doi.org/10.1016/j.labinv.2024.102111PMid:39053633
75. Gao Y, Wen P, Liu Y, Sun Y, Qian H, Zhang X, et al. Application of artificial intelligence in the diagnosis of malignant digestive tract tumors: focusing on opportunities and challenges in endoscopy and pathology. Journal of Translational Medicine. 2025;23(1):412. https://doi.org/10.1186/s12967-025-06428-z PMid:40205603 PMCid:PMC11983949
76. Srivastav AK, Mishra MK, Lillard Jr JW, Singh R. Transforming pharmacogenomics and CRISPR gene editing with the power of artificial intelligence for precision medicine. Pharmaceutics. 2025;17(5):555. https://doi.org/10.3390/pharmaceutics17050555 PMid:40430848 PMCid:PMC12114816
77. Koh HYK, Lam UTF, Ban KH-K, Chen ES. Machine learning optimized DriverDetect software for high precision prediction of deleterious mutations in human cancers. Scientific Reports. 2024;14(1):22618. https://doi.org/10.1038/s41598-024-71422-2 PMid:39349509 PMCid:PMC11442673
78. Pillay TS, Khan AI, Yenice S. Artificial intelligence (AI) in point-of-care testing. Clinica Chimica Acta. 2025;574:120341. https://doi.org/10.1016/j.cca.2025.120341 PMid:40324611
79. Viswanathan VS, Parmar V, Madabhushi A. Towards equitable AI in oncology. Nature Reviews Clinical Oncology. 2024;21(8):628-37. https://doi.org/10.1038/s41571-024-00909-8 PMid:38849530
80. Kalsi S, French H, Chhaya S, Madani H, Mir R, Anosova A, et al. The evolving role of artificial intelligence in radiotherapy treatment planning-A literature review. Clinical Oncology. 2024;36(10):596-605. https://doi.org/10.1016/j.clon.2024.06.005 PMid:38981781
81. Sheng Y, Zhang J, Ge Y, Li X, Wang W, Stephens H, et al. Artificial intelligence applications in intensity modulated radiation treatment planning: an overview. Quantitative Imaging in Medicine and Surgery. 2021;11(12):4859. https://doi.org/10.21037/qims-21-208 PMid:34888195 PMCid:PMC8611458
82. Dona Lemus OM, Cao M, Cai B, Cummings M, Zheng D. Adaptive radiotherapy: next-generation radiotherapy. Cancers. 2024;16(6):1206. https://doi.org/10.3390/cancers16061206 PMid:38539540 PMCid:PMC10968833
83. Jeong C, Goh Y, Kwak J. Challenges and opportunities to integrate artificial intelligence in radiation oncology: a narrative review. The Ewha Medical Journal. 2024;47(4). https://doi.org/10.12771/emj.2024.e49 PMid:40704006 PMCid:PMC12093566
84. Conroy L, Winter J, Khalifa A, Tsui G, Berlin A, Purdie T. Artificial intelligence for radiation treatment planning: Bridging gaps

from retrospective promise to clinical reality. Clinical Oncology. 2025;37:103630. https://doi.org/10.1016/j.clon.2024.08.005 PMid:39531894

85. Abejas AG, Santos DG, Costa FL, Botejara AC, Mota-Filipe H, Vergés ÀS. Ethical Challenges and Opportunities of AI in End-of-Life Palliative Care: Integrative Review. Interactive Journal of Medical Research. 2025;14(1):e73517. https://doi.org/10.2196/73517 PMid:40302210 PMCid:PMC12120364

86. Riaz IB, Khan MA, Osterman TJ. Artificial intelligence across the cancer care continuum. Cancer. 2025;131(16):e70050. https://doi.org/10.1002/cncr.70050 PMid:40810209 PMCid:PMC12351523

87. Saber AF, Ahmed SK, Hussein S, Qurbani K. Artificial intelligence-assisted nursing interventions in psychiatry for oral cancer patients: a concise narrative review. Oral Oncology Reports. 2024;10:100343. https://doi.org/10.1016/j.oor.2024.100343

88. Razavi J, Dhafar HO, BaHammam AS. Transforming health care with artificial intelligence: Regulations, challenges, and future directions. Saudi Journal for Health Sciences. 2025;14(1):11-22. https://doi.org/10.4103/sjhs.sjhs_26_25

89. Rabbani SA, El-Tanani M, Sharma S, Rabbani SS, El-Tanani Y, Kumar R, et al. Generative Artificial Intelligence in Healthcare: Applications, Implementation Challenges, and Future Directions. BioMedInformatics. 2025;5(3):37 https://doi.org/10.3390/biomedinformatics5030037