APPLICATION OF ARTIFICIAL INTELLIGENCE IN THE PREDICTION OF ONCOLOGICAL PROGNOSIS: INNOVATIONS, OBSTACLES AND POSSIBILITIES FOR THERAPEUTIC PERSONALIZATION

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ABSTRACT

This systematic review investigates the application of Artificial Intelligence (AI) in the prediction of cancer prognosis, with an emphasis on the personalization of treatments. We analyzed 78 studies that used AI algorithms, such as Convolutional Neural Networks (CNNs) and Support Vector Machines (SVMs), in breast, lung, colorectal, and prostate cancers. The main outcomes addressed recurrence, survival, and therapeutic response. The results demonstrated that AI improves accuracy in identifying relapses and predicting treatment response, facilitating personalized interventions. However, the heterogeneity of

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the data and the lack of standardization represent obstacles to large-scale clinical implementation. The review also highlights the future prospects for integrating AI into precision medicine, favoring the development of more effective and individualized cancer treatments. It is concluded that, although the advances are promising, collaboration between health professionals and AI, the establishment of clear regulations, and the construction of consistent databases are fundamental to the success of AI in oncology.

Keywords: Artificial Intelligence. Oncology. Prognosis. Forecast. Precision Medicine.

INTRODUCTION

Artificial intelligence (AI), despite being a largely contemporary field, has roots dating back to the 1940s. During this period, Isaac Asimov's work, specifically the short story Runaround, presented innovative concepts by describing robots programmed to follow ethical principles outlined in the so-called "Three Laws of Robotics". These laws established that a robot could not harm a human being or allow, by omission, such damage to occur; he was to obey human commands, unless they conflicted with the first law; and it was supposed to protect its own existence, so long as that protection did not violate the previous laws. At the same time, figures such as Vannevar Bush, in his publication As We May Think (1945), anticipated a future in which computers would play an essential role in supporting human activities. Complementing this view, John Von Neumann challenged the limits of computing by stating that any task not achievable by a machine could be programmed to be executed, driving the evolution of automated systems and laying the foundations for the development of AI in the twentieth century (Akabane, 2024)

Artificial Intelligence (AI) has stood out as an innovative technology in the field of oncology, offering new approaches to predicting prognoses and personalizing treatments. AI uses advanced algorithms, such as Convolutional Neural Networks (CNNs) and Support Vector Machines (SVM), which can process large volumes of clinical, genomic, and imaging data, enabling more accurate and efficient analysis of medical data (Lecun et al.., 2015; Vapnik, 1998).

The application of AI in oncology has been widely explored in different types of cancer, such as breast, lung, colorectal, and prostate, with promising results in predicting recurrence, survival, and response to treatment (Smith et al., 2020; Wu et al., 2023).

In clinical practice, AI can integrate different types of data to more accurately predict the course of the disease, adjusting treatments according to the individual characteristics of each patient (Collins & Varmus, 2015). For example, AI-based predictive models are widely used in medical image analysis, such as mammograms and CT scans, where they identify complex patterns that aid in early diagnosis and monitoring of tumor evolution (Chang et al., 2021).

While AI has shown great potential in oncology, there are still challenges to overcome. The heterogeneity of the data used in the studies, the need for large volumes of data for model training, and the lack of standardization among algorithms are obstacles that hinder large-scale clinical application (Esteva et al., 2017). In addition, the acceptance and use of AI in the clinical setting depends on healthcare professionals' familiarity with these technologies and the creation of regulations that ensure the safety and effectiveness of these tools (Yu et al., 2018).

Given this scenario, the objectives of this systematic review are: (1) to identify the main AI models used in the prediction of cancer prognosis; (2) to evaluate the effectiveness of AI in different types of cancer; and (3) discuss the challenges and opportunities related to the integration of AI in oncology clinical practice.

THEORETICAL FRAMEWORK

The use of Artificial Intelligence (AI) in oncology is based on theoretical approaches that combine knowledge of machine learning, analysis of clinical and genomic data, and precision medicine. AI provides an analytical interface that allows the prediction of clinical outcomes, facilitating the treatment of various malignancies and improving the personalization of medical care (Chen *et al*., 2024).

THEORETICAL APPROACHES TO AI IN ONCOLOGY

The theoretical bases of the application of AI in oncology include the use of supervised models, such as CNNs and SVMs, which are widely employed in the analysis of medical images and clinical data. Convolutional Neural Networks (CNNs), for example, have been successfully used to identify patterns in mammogram and CT scan images, allowing for earlier and more accurate diagnoses (Lecun *et al*., 2015). Studies suggest that AI may provide a more efficient approach to predicting relapse and treatment response by dynamically adjusting according to patient data (Smith *et al.*, 2020).

In addition, Support Vector Machines (SVM) are effective in the analysis of clinical and genomic data, being successfully applied in the prediction of survival in patients with lung and breast cancer (Vapnik, 1998). Integrating different types of data—clinical, genomic, and imaging—into a single predictive model has been a promising approach in precision medicine, allowing for a more comprehensive and personalized assessment of cancer patients (Collins & Varmus, 2015).

AI MODELS IN THE PREDICTION OF ONCOLOGICAL PROGNOSES

AI models applied to oncology vary widely according to the type of cancer and the clinical outcomes analyzed. In breast cancer treatment, for example, CNNs are used to predict relapse and response to chemotherapy based on mammography images, which allows for a more personalized and efficient approach (Chang *et al*., 2021). In lung cancer, SVMs are often used to predict survival based on genomic and clinical data, allowing for better patient stratification (Wu *et al*., 2023).

For colorectal cancer, models such as Random Forests have shown great efficacy in combining clinical and genomic variables to predict relapse and response to treatment, providing a more accurate assessment of clinical outcomes (Smith *et al*., 2020). The integration of genetic biomarkers with clinical and imaging data represents a significant advance in the personalization of treatments, enabling better management of therapeutic resources (Liu *et al*., 2022).

CHALLENGES AND OPPORTUNITIES IN THE USE OF AI IN ONCOLOGY

Despite the significant advantages, there are still challenges that limit the adoption of AI in oncology clinical practice. One of the main challenges is the heterogeneity of the data used, which can compromise the accuracy of predictive models when applied to different populations (Esteva *et al*., 2017). In addition, the lack of standardization between algorithms makes it difficult to replicate results between different studies and clinical centers.

Another challenge is the need for large volumes of data for effective training of AI models. Studies with smaller sample sizes tend to have lower accuracy, which highlights the importance of developing robust and widely accessible clinical databases to ensure the effectiveness of models (Sun *et al*., 2017). Also, ethical issues and the lack of clear regulation on the use of AI in clinical diagnostics are also barriers to be overcome (Yu *et al*., 2018).

Despite these limitations, the future opportunities for the use of AI in oncology are vast. Precision medicine, coupled with the use of AI, can transform the way cancer treatments are developed, allowing each patient to receive personalized therapy based on integrated molecular and clinical data (Collins & Varmus, 2015). Additionally, the development of hybrid models, which combine different machine learning approaches, can help overcome some of the current limitations, improving the accuracy of prognoses and the personalization of treatments (Liu *et al*., 2022).

METHODOLOGY

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, ensuring the transparency and replicability of the processes used (Moher *et al*., 2009). The objective was to synthesize evidence on the use of Artificial Intelligence (AI) in predicting prognoses in cancer patients, examining the most effective techniques, their applications and the reported limitations.

TYPE OF STUDY

This systematic review followed the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), ensuring transparency and replicability of the processes (Moher *et al*., 2009). The study was conducted to compile and critically analyze the use of AI in predicting cancer prognosis, focusing on machine learning models applied to different types of cancer.

SAMPLE SELECTION AND DATA SOURCES

Studies published between 2019 and 2024 were included, focusing on recent advances in the application of AI in oncology. Databases consulted included PubMed, Web of Science, Scopus, and IEEE Xplore, due to their relevance to the medical and technological field. The Boolean operators used were ("Artificial Intelligence" OR "Machine Learning") AND ("Oncology" OR "Cancer") AND ("Prognosis"). The initial search resulted in 8796 articles, and after applying the inclusion and exclusion criteria, 78 studies were selected for full reading.

Inclusion criteria were peer-reviewed studies, which applied AI to predict prognosis in cancer patients, including relapse, survival, and response to treatment; Publications in English or Portuguese, between 2019 and 2024; Studies that used clinical, genomic, or imaging data (e.g., MRI, PET, CT).

We chose to exclude narrative reviews, letters to the editor, and opinion studies from the survey; Studies without validation of AI models or without clear clinical outcomes.

DATA COLLECTION

Data collection was carried out independently by two reviewers, according to the methodological guidelines of systematic reviews (Higgins *et al*., 2021). The reviewers assessed titles and abstracts to identify studies that met the inclusion criteria. The selected articles were read in full, and the following information was extracted: (1) Author(s); (2) Year of publication; (3) Geographic location of the study; (4) Type of cancer addressed; (5) AI models used; (6) Data used (clinical, genomic, imaging, etc.); (7) Clinical outcomes (survival, relapse, response to treatment).

DATA ANALYSIS

The data were analyzed qualitatively, using a narrative synthesis of the results. The AI models were evaluated for precision, accuracy, sensitivity, and specificity in oncological prognosis. The main techniques employed were convolutional neural networks (CNNs), support vector machines (SVM) and random forests.

ETHICAL CONSIDERATIONS

Although this review did not involve direct data collection with human participants, all included studies were assessed for compliance with ethical standards, including obtaining informed consent and approval by research ethics committees, in accordance with established international guidelines (World Medical Association, 2013).

STUDY LIMITATIONS

The main limitations of this review include the heterogeneity of the selected studies, which vary widely in terms of methodologies, types of cancer, and use of different AI models. In addition, the lack of consistent quantitative data between studies prevented a formal meta-analysis from being conducted, restricting the synthesis of findings to a qualitative analysis (Ng *et al*., 2024; Dalko *et al*., 2024). Another point is that the inclusion of articles in only two languages (English and Portuguese) may have limited the breadth of the review.

RESULTS AND DISCUSSIONS

RESULTS

After screening the 78 selected articles, several approaches to the application of Artificial Intelligence (AI) in the prediction of cancer prognoses were identified. The studies were grouped according to the type of cancer, the AI techniques used, and the clinical outcomes observed.

TYPES OF CANCER ADDRESSED

The main types of cancer explored in the included studies were:

Breast Cancer: This was the main focus, appearing in 40% of the studies analyzed. AI was applied to predict relapse, response to treatment (such as chemotherapy and hormone therapy), and overall survival. Convolutional Neural Networks (CNNs) have been widely used for medical image analysis (Wang *et al*., 2021; Li *et al*., 2020).

Lung Cancer: In 30% of the studies, AI was applied in predicting survival in lung cancer patients undergoing treatments such as chemotherapy and immunotherapy. Support Vector Machines (SVM) and CNNs were used to analyze medical images, such as Computed Tomography (CT) and PET (Zhou *et al*., 2019; Kim *et al*., 2022).

Colorectal Cancer: Accounted for 20% of studies, with AI being used primarily to predict relapse and response to treatment, employing clinical and genomic data. Random Forests were often used in these studies (Smith *et al*., 2020).

Prostate Cancer: Appeared in 10% of studies, with AI being applied to predict tumor aggressiveness and response to radiation therapy, utilizing techniques such as CNNs and medical image analysis (Johnson *et al*., 2019).

AI MODELS USED

The main AI models employed in the reviewed studies were:

Convolutional Neural Networks (CNNs): Used in 50% of studies, especially in the analysis of medical images, such as mammograms, CT scans, and MRIs. CNNs have performed highly in predicting tumor recurrence and response (Chang *et al*., 2021; Liu *et al*., 2022).

Support Vector Machines (SVM): Accounting for 30% of studies, SVMs were primarily used to classify clinical and molecular data in lung and breast cancers, demonstrating efficacy in predicting prognosis based on individual tumor characteristics (Zhang *et al*., 2020; Wu *et al*., 2023).

Random Forests: Used in 20% of the studies, these techniques were used to combine clinical and genomic variables in prediction models, with emphasis on the analysis of large volumes of data and prediction of complex clinical outcomes (Kim *et al*., 2022).

PREDICTION OF CLINICAL OUTCOMES

The main outcomes predicted by the AI models included:

Overall Survival: In 60% of studies, AI models accurately predicted the survival of patients at different stages of cancer, using clinical and genetic data (Zhou *et al*., 2019).

Relapse: In 50% of studies, AI was applied to predict tumor recurrence, identifying patients at higher risk of disease recurrence after initial treatment (Smith *et al*., 2020; Li *et al*., 2020).

Response to Treatment: In 40% of studies, AI was used to predict patients' response to treatments such as chemotherapy, radiation therapy, or immunotherapy, allowing for the personalization of interventions according to the patient's profile (Chang *et al*., 2021).

PERFORMANCE OF AI MODELS

The evaluation of the performance of the AI models was carried out based on the following metrics:

Accuracy: Most studies have reported an accuracy of more than 80% in predicting prognosis, evidencing the efficiency of AI compared to conventional methods (Liu *et al*., 2022; Kim *et al*., 2022).

Accuracy and Sensitivity: Models such as CNNs have shown accuracy and sensitivity above 85%, especially in identifying patterns in medical imaging (Chang *et al*., 2021).

ROC (Receiver Operating Characteristic) Curves: In more than 60% of the studies, ROC Curves performed excellently, with areas under the curve (AUC) ranging between 0.85 and 0.95, indicating the reliability of AI models in predicting clinical outcomes (Wu *et al*., 2023).

LIMITATIONS OBSERVED

While the results are promising, some limitations were highlighted in the reviewed studies:

Data Heterogeneity: The diversity of data types (imaging, genomic, clinical) and different treatment protocols made it difficult to directly compare results between studies (Smith *et al*., 2020; Johnson *et al*., 2019).

Need for Large Volumes of Data: Many AI models require large amounts of data to be trained effectively. Studies with a smaller number of patients showed lower performance, evidencing the need for robust samples to ensure the effectiveness of the models (Zhou *et al*., 2019; Li *et al*., 2020).

Clinical Integration: Several studies have pointed to difficulties in integrating AI models into the clinical flow, due to barriers such as resistance from healthcare professionals, lack of familiarity with technologies, and the absence of clear regulations (Kim *et al*., 2022).

DISCUSSION

The results of this systematic review reinforce the growing role of Artificial Intelligence (AI) in predicting cancer prognosis, demonstrating that, when well applied, AI can improve accuracy in detecting recurrence, predict treatment response, and prolong patient survival. Next, we discuss the main findings in light of the current literature, highlighting the implications, challenges, and opportunities for future studies.

The findings confirm that AI models have shown high accuracy on several fronts of oncology. In particular, Convolutional Neural Networks (CNNs) excel at treating medical images such as mammograms and CT scans, identifying complex patterns that are not easily detected by conventional methods (Lecun *et al*., 2015). CNNs have played a crucial role in predicting recurrence and assessing tumor response (Zhang *et al*., 2020).

In addition, Support Vector Machines (SVM) have been shown to be effective in analyzing clinical and genomic data, especially in studies focused on lung cancer and breast cancer, corroborating previous studies that have shown the potential of these techniques to predict survival based on specific genetic characteristics (Vapnik, 1998; Wu *et al*., 2023).

Despite the advances, the application of AI in oncology still faces significant challenges. The heterogeneity of the data used in the studies — which range from imaging, genomic and clinical data — presented difficulties in comparing results between different models. The integration of these different types of data into a single effective predictive model is still an unsolved problem (Esteva *et al*., 2017).

Another limiting factor was the availability of large volumes of data. While models such as CNNs and Random Forests have demonstrated high performance in studies with large samples, in studies with a limited number of patients, performance has dropped significantly, indicating that AI models require a considerable amount of data to achieve robust results (Sun *et al*., 2017). This may explain why some studies with smaller sample sizes had an accuracy of less than 80% (Smith *et al*., 2020).

The integration of AI into the clinical setting also faces barriers. While AI models have shown impressive performance in studies, their application in real-world clinical scenarios is complex. Many healthcare professionals are still resistant to using AI-based systems due to a lack of familiarity with these technologies and ethical concerns related to the transparency of algorithms (Topol, 2019).

The absence of clear regulation is also a limiting factor. The development of regulatory guidelines for the approval and use of AI in clinical diagnostics is urgent to ensure that these tools are applied safely and effectively, providing confidence to practitioners and patients (Yu *et al*., 2018).

Despite the limitations, the results point to a promising future. The increasing use of genetic biomarkers and the application of precision medicine can help improve predictive models by integrating molecular and clinical data with unprecedented accuracy (Collins; Varmus, 2015). The development of hybrid models, which combine deep neural networks with classical supervised learning, also has the potential to address some of the limitations noted in this review (Liu *et al*., 2022). The personalization of cancer treatments with AI promises to reduce side effects and improve the quality of life of patients, since the models can identify patients who will respond best to certain therapies, optimizing health resources and avoiding unnecessary treatments (Zhou *et al*., 2019).

Despite efforts to conduct a comprehensive systematic review, this review faces some limitations. First, the review was restricted to articles in English and Portuguese, which may have limited the scope of studies evaluated. In addition, many of the included studies were conducted in homogeneous patient populations, which may affect the generalizability of results to more diverse populations (Johnson *et al*., 2019).

The absence of consistent quantitative data prevented the performance of a formal meta-analysis, limiting the synthesis of the findings to a qualitative analysis. Future studies should seek to integrate a greater amount of quantitative data and consider conducting meta-analyses to gain a more robust view of the impact of AI in oncology (Kim *et al*., 2022).

CONCLUSION

This systematic review analyzed studies on the application of Artificial Intelligence (AI) in the prediction of oncological prognosis, covering types of cancer such as breast, lung, colorectal, and prostate. The findings confirm that AI is a promising and effective tool, offering significant advantages compared to traditional prediction and diagnostic methods. The ability to process large volumes of clinical, genomic, and imaging data allows AI models to identify complex patterns and provide more accurate and personalized prognoses tailored to each patient's individual characteristics.

The reviewed studies demonstrated that AI is particularly effective in predicting relapse and survival, especially in cases of breast and lung cancer, where models such as Convolutional Neural Networks (CNNs) and Support Vector Machines (SVM) have shown high accuracy in analyzing imaging and clinical data. In addition, AI has excelled in personalizing treatments, predicting patients' response to therapies such as chemotherapy and radiotherapy, allowing for more targeted interventions and improving clinical outcomes.

Despite the advances evidenced, the review identified important challenges, such as the heterogeneity of the data and the need for large volumes of information to train the AI models effectively. In addition, the integration of these systems into the clinical setting still faces significant barriers, such as the lack of clear regulation, resistance from healthcare professionals, and the high cost associated with implementing advanced technologies.

It is essential to highlight that, although AI offers substantial support to medical practice, it does not replace the knowledge and judgment of health professionals. AI acts as a complementary tool, providing valuable insights to support decision-making, but clinical experience and expertise remain irreplaceable in cancer diagnosis and treatment. The success of AI implementation depends on collaboration between physicians and data engineers, ensuring that the recommendations generated by the algorithms are correctly interpreted and applied in the clinical context.

The contributions of this study are relevant as they reinforce the potential of AI as a complementary and, in some cases, superior tool to traditional prediction methods in oncology. The practical implications suggest that AI can transform the approach to cancer treatments, allowing the creation of personalized therapies that increase efficacy and reduce adverse effects. For the future, it is essential that new research explores the integration of AI with other emerging technologies, such as genomic biomarkers, and the standardization of AI's clinical use protocols, to optimize treatments and adjust predictions according to individual patient responses.

In summary, Artificial Intelligence is consolidating itself as a promising approach in oncology, with the potential to redefine the limits of therapeutic prediction and personalization. By providing an adaptive, accurate method capable of handling growing volumes of clinical data, AI contributes to a new era of treatments that value personalization and clinical effectiveness. However, the irreplaceable role of physicians, who interpret data and adjust clinical decisions, will continue to be essential to ensure quality of care and successful treatments.

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