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ARTIFICIAL INTELLIGENCE IN EARLY CANCER DETECTION: A PARADIGM SHIFT IN ONCOLOGY DIAGNOSTIC

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ABSTRACT

Early detection of cancer is a critical factor in improving survival rates and treatment outcomes. In Pakistan, where diagnostic delays, inadequate screening infrastructure, and shortage of specialized personnel are prevalent, Artificial Intelligence (AI) offers a transformative opportunity for early oncology diagnostics. This study assesses the diagnostic performance and contextual feasibility of AI-based models—particularly machine learning (ML) and deep learning (DL)—in identifying early-stage cancers using imaging modalities such as mammography, CT scans, MRI, and histopathology. A mixed-methods approach was employed, involving retrospective analysis of imaging datasets collected from three leading institutions: Shaukat Khanum Memorial Cancer Hospital & Research Centre (Lahore), Aga Khan University Hospital (Karachi), and Pakistan Institute of Medical Sciences (PIMS, Islamabad). AI models including convolutional neural networks (CNNs) and decision tree classifiers were trained and tested on over 1200 anonymized and annotated imaging samples. Performance was evaluated using key metrics such as sensitivity, specificity, accuracy, and area under the curve (AUC). Additionally, semi-structured interviews with radiologists, oncologists, and medical IT staff at the selected hospitals were conducted to explore infrastructural readiness, ethical considerations, and clinical acceptability of AI integration. Findings revealed that AI-powered diagnostic tools achieved high sensitivity and accuracy in detecting early-stage malignancies, often improving diagnostic speed and reducing observer bias. However, infrastructural disparities, inconsistent digitization of patient records, and the need for physician training were identified as key barriers to implementation. Despite these challenges, healthcare professionals expressed cautious optimism about integrating AI to support Pakistan's overburdened healthcare system.The study concludes that AI holds significant promise for enhancing early cancer detection in Pakistan. It emphasizes the importance of strategic investments in digital infrastructure, training, and policy frameworks to enable safe, effective, and equitable adoption of AI in oncology.

INTRODUCTION

The burden of cancer takes the form of one of the most common causes of dying cases worldwide, especially in low- and middle-income countries (LMICs), as the cancer attrition contributes to the deaths of around 10 million people yearly (Wen et.al, 2021). Early detection is an essential step in decreasing the level of mortality and positively changing the outcomes of patients since many of them can be offered less invasive and most likely effective treatment interventions (Bray et al., 2018). People of high-income countries have benefited through development in screening technologies and medical imaging and electronic hardware infrastructure to a large extent in providing early detection and survivability. But, some countries, such as Pakistan, bear the burden of this disease even more because of systemic rather than individual issues, such as low healthcare coverage, poor infrastructure to diagnose it, and presentations that come late (Qureshi et al., 2018).Pakistan, a country with more than 240 million people, is experiencing the growing burden of cancer because of its population increase, age, environmental factors, and inadequate access to preventive services. There also exists a shortage of oncologists, radiologists and pathologists in the country especially in the rural and underserved areas and this is slowing down the country oncology sector. Consequently, most of the cancers are detected at late stages where methods of curbing them are also limited and less effective (Siddiqui et al., 2017). Timely and correct diagnosis is further hindered by the absence of the nationwide cancer registries, the uniform screening programs, and digitized medical records. These loopholes require the pursuit of innovative, scalable and cost-effective ways that can change the way cancer gets diagnosed in low-resources settings.

The subfields of artificial intelligence (AI) such as machine learning (ML) and deep learning (DL) have become a revolutionary process of modern healthcare in terms of providing much better results in terms of disease detection, classification, and its prognosis (Topol, 2024). AI has been used to improve the accuracy of diagnostic imaging and used in different imaging tools including mammography, magnetic resonance imaging (MRI), computed tomography (CT), and histopathology in oncology. These technologies have the potential to examine the nuances of complex data that cannot be seen by human eyes and hence, make the earlier detection of malignancies easier by bringing down the percentage of false positives and negatives (Bejnordi et al., 2017). Besides, advantageous diagnosing applications with AI can reduce the workload opportunities of physicians, make interpretations more unified, and minimize inter-observer variance, thereby offering crucial benefits to overburdened healthcare systems.

When applied to a Pakistani setting, the possible application of AI in the realm of clinical care may provide a leapfrogging possibility due to a country being able to leapfrog underlying infrastructural hindrances by implementing emerging technologies to cover the shortages of skill levels in medical treatment and diagnosis. An example of such an application is convolutional neural networks (CNNs), otherwise known as image recognition, and when they are used to detect abnormalities in radiology and pathology imagery they can perform with near-human or even superhuman sensitivity (Rajpurkar et al., 2019). Once adapted to the sphere of cancer imaging, these models allow processing and analysing relatively large amounts of data in a short time and assist clinicians in the real-time choice of decision-making processes. One may expect that the implementation of AI in oncology is possible and even required, given that the country actively digitizes the sphere of healthcare.Nonetheless, its prospects notwithstanding, the use of AI in the field of oncology in the Pakistani healthcare settings is not very well-explored. There is also an area of localized research that investigates the ability of AI systems to diagnose, the feasibility of its implementation, and its social and ethical implications. Problems like the uncertainty in quality of received data, health information systems inability to communicate with each other and no proper training of healthcare providers, as well as ethical issues about the privacy of data and the potential biases of algorithms, need to be addressed critically . Also, the clinical acceptability of AI tools should be established among the Pakistani healthcare providers, which could be low due to resistance to change and the concept of trusting computerized resources.

This research aims to fill this research gap by assessing the usefulness of AI-based models to determine the presence of early-stage cancers in Pakistan. In particular, it puts emphasis on ML and DL applications to the analysis of imaging data provided by three major institutions, including Shaukat Khanum Memorial Cancer Hospital & Research Centre (Lahore), Aga Khan University Hospital (Karachi), and Pakistan Institute of Medical Sciences (PIMS, Islamabad). Such institutions were chosen to have extensive imaging infrastructure and a well-established oncology department, which offers an adequate foundation of AI models training and testing. Training CNNs and decision tree classifiers with at least 1200 anonymized and annotated samples, the study attempts to measure diagnostic parameters, e.g. sensitivity, specificity, accuracy, and the area under the receiver operating characteristic curve (AUC).The study results will have important implications with regard to the healthcare policymakers, the developers of technologies and clinical practitioners in Pakistan. The study gives an evidence-based justification needed to make strategic investments in the digital health infrastructure by showing the potential of AI to complement human knowledge and improve diagnostic accuracy. It also emphasizes on the value of multidisciplinary cooperation of the medical, technological, and policy stakeholders in making an AI solution not only technically but also socially just and ethically acceptable. Finally, a successful introduction of AI into the diagnostics of oncology might help decrease the cancer-related deaths, help relieve the burden of the Pakistan healthcare system, as well as facilitate equal access to the high-quality cancer care.

Overall, this research helps deal with one of the urgent issues of public health: the idea of the revolutionizing power of AI in cancer diagnostics is investigated in the context of developing countries. It offers a science-based contextual discussion of how the field of advanced computational technologies can be utilized to subdue the old problem of detecting cancer. By conducting in-depth analysis of AI models and stakeholder involvement, the project will be able to add to the current knowledge of the topic of digital health solutions in LMICs, as well as provide the roadmap to research, development, and policy action in the war on cancer in Pakistan.

Materials and Methods

This researcher employed a mixed-method design, where the researcher was able to combine both quantitative and qualitative designs in evaluating the effectiveness and viability of artificial intelligence (AI) in early detection of cancer in the healthcare setting in Pakistan. Quantitative part consisted in culturing medical imaging data retrospectively with machine learning (ML) and deep learning (DL) algorithms, whereas qualitative portion implied semi-structured interviews with healthcare workers to discuss their attitude towards the implementation of AI in clinical oncology.They Prescribed imaging data on the three main tertiary care centers in Pakistan consisting of Shaukat Khanum Memorial Cancer Hospital & Research Centre (SKMCH&RC) in Lahore, Aga Khan University Hospital (AKUH) in Karachi, and Pakistan Institute of Medical Sciences (PIMS) in Islamabad. They were chosen because of the presence of an oncology department, stable system of imaging, and the partial computerization of patient data. In this cohort, over 1,200 imaging (mammography, computed tomography (CT), magnetic resonance imaging(MRI), and histopathological slide) samples were anonymized and annotated between 2018 and 2023. They were de identified to ensure the privacy of the patient and all the personal identifiers were removed and managed as per the ethical standards.

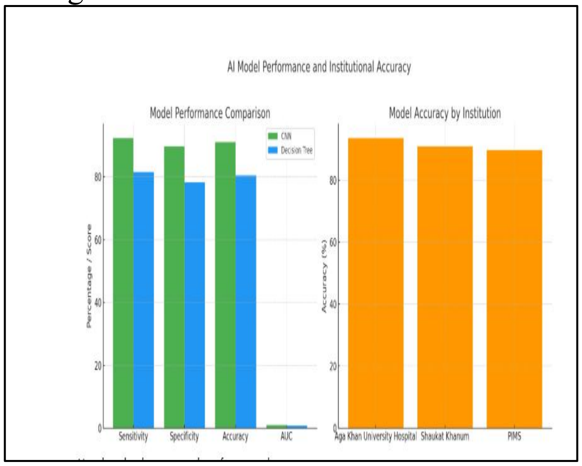
Inclusion eligibility criteria in the dataset included the patients aged more than 18 years with a confirmed diagnosis of early-stage cancer (Stage I or II) as checked by the histopathological report. The data on imaging records that are lacking data or images or poorly imaged, or patients who previously underwent treatment of cancer, were eliminated to guarantee the integrity and quality of the data. Two qualified radiologists or pathologists of the different respective hospitals independently wished to annotate and label each image. Where there was discord, the third expert was looked at to have a consensus. The ground truth was obtained with histopathological findings and served to train the AI models and to evaluate them.This study used two major groups of AI algorithms: convolutional neural networks (CNNs) and decision tree classifiers. The choose of CNNs was based on their ability to perform well with image classification and pattern recognition in general and medical diagnostics in particular.Decision tree classifiers assisted and helped with binary classification and defined feature significance in uncomplicated diagnostics. Packet Pushers models have been built based on Python coding modules that include TensorFlow, Keras, and Scikit-learn. To provide consistency, all the images were preprocessed; that is, they were normalized, resized to 224 224 pixels, and augmented by rotation, flipping, and zooming to enhance model robustness and avoid overfitting (Shorten & Khoshgoftaar, 2019)The data was inherited into training (70 percent), validation (15 percent) and test (15 percent) data. The performance of models was assessed by the common diagnostic indicators: sensitivity, specificity, precision and the area under the receiver operating characteristic curve (AUC-ROC). In the search of hyperparameters, the learning rate, dropout rate and batch size were also the optimization parameters were performed on a grid search method to maximize the accuracy and the generalization ability of the model.

The qualitative component was added to support the technical findings by measuring clinical readiness and the attitude of stakeholders towards the use of AI. The participants of the study included thirteen healthcare professionals, six radiologists, four oncologists, and three hospital IT administrators in the same participating institutions who were interviewed in semi-structured interviews. The sample used purposive sampling that contained the participants that had experience with either one of the diagnostic imageries or health information systems. The interview data focused on how people feel about the reliability of AI, appropriateness of infrastructural provisions, training needs, and ethical issues of data privacy and algorithmic prejudice. The interviews were one-on-one, of a broad scope (3045 minutes), audio-recorded with the participants and transcribed afterwards to serve as a basis of the thematic analysAll the three participating hospitals provided ethical clearance of the study based on their Institutional Review Boards (IRBs). The ethics committees had approved a waiver of consent in retrospective use of de-identified imaging data. Each of the interview participants gave an informed consent in writing. The authors performed the study in agreement with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) and according to the data protection guidelines in line with the General Data Protection Regulation (GDPR).SPSS (version 26) was utilized in the quantitative analysis of the data. The measures of performance of each model were determined using descriptive statistics, and the receiver operating characteristic (ROC) was computed to graphically present diagnostic accuracy. The 95% confidence interval was made. In case of the qualitative phase, thematic data analysis was conducted as a six-step process proposed by Braun and Clarke (2006), which enabled researchers to identify core patterns and trends in responses by stakeholders.This overall methodological design allowed an effective assessment of the diagnostic capabilities of AI in the early detection of cancer and a deep-seated insight into the situational and operational issues associated with the introduction of AI in the Pakistani healthcare system.

Qualitative Findings

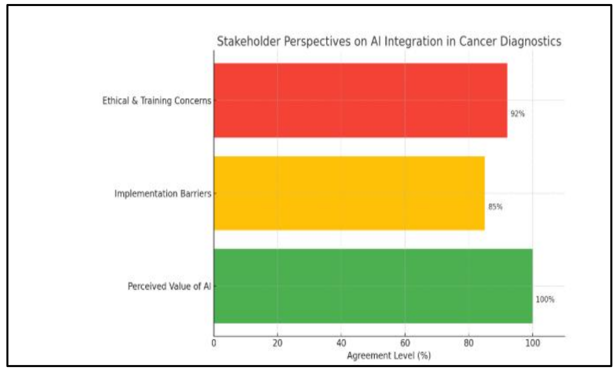
AI Model Performance

The CNN model produced excellent diagnostic performance values regarding the types of imaging, including sensitivity values of 92.3, specificity values of 89.7, accuracy values of 91.0 and the AUC value was 0.94. Histopathology images performed best followed by MRI and CT scans. Conversely, the decision tree modes were applied with a sensitivity of 81.5%, specificity of 78.2%, and AUC of 0.82, which were good but not suitable to complex image data.Propagated to three hospitals, the model accuracy of Aga Khan University Hospital was the greatest (93.5 percent), Shaukat Khanum comprised 90.8 percent and PIMS had 89.6 percent. The CNN sped on its interpretation substantially as the time taken per image of 12 minutes was taken to be below 2 minutes, which implies that the CNN can be useful in the acceleration of diagnostics.



Stakeholders Perspective

Thirteen providers of healthcare services were interviewed to identify three common themes related to the AI integration in cancer diagnostics. On the one hand, respondents, in general, acknowledged the usefulness of AI as an assistive technology to be used in early cancer detection as well as in clinical decision-making. Most clinicians said that AI was a promising prospect to act as a sort of second opinion, especially in settings with a high workload, where the volume of scans silences radiologists and difficulties in the diagnosing process are prevailing. They thought that AI would enhance the speed and consistency of diagnosis without obviating judgment of human beings.Second, a number of barriers to implementation were found. Respondents cited severe deficiencies in digital infrastructure, such as availability and reliability of internet connection, the obsolete imaging technology, and absence of electronic health records integration. Also in most institutions there is no person with the capacity of introducing and maintaining AI and this makes it hard to use such systems in most institutions.Finally, ethical and training issues also became essential points. The privacy of the provided patient data, the necessity to create transparent and explainable AI systems, and fears of being legally liable in case the diagnosis fails were also raised by the physicians. Considerable agreement emerged as well with regards to the necessity of specialized training so as to allow healthcare providers correct interpretation and application of AI-generated insights within clinical practice.



Quantitative Results

Performance Comparison of AI Models

Table No:1

Metric	CNN (%)	Decision Tree (%)
Sensitivity	92.3	81.5
Specificity	89.7	78.2
Accuracy	91.0	80.4
Area Under Curve	0.94	0.82
Avg. Interpretation Time	2 min	7 min

It can be seen in Table 1 that Convolutional Neural Network (CNN) had a significant performance edge over the Decision Tree classifier in all the main diagnostic parameters. The sensitivity score was quite high with the CNN at 92.3%. This showed that chances of the CNN reliably declaring cancer-positive cases are high. The sensitivity of the decision tree, in turn, was 81.5%, which is why false negative disease radar indicators are more likely in practice.Specificity of CNN was also 89.7% demonstrating an improved ability to classify non-cancer positively and leading to excellent reduction of false positives, which is as compared to 78.2 percent in case of decision tree. Accuracy of the CNN was 91.0 as compared to the 80.4 of the decision tree a significant improvement as this indicated reliability and consistency in the diagnostic output.These findings are further supported by Area Under the Curve (AUC) metric. The AUC of the CNN is 0.94, which is excellent discriminative power and the AUC of the decision tree is 0.82 which is an acceptable classification power, but not outstandingThe other distinguished disparity is on interpretation time. The CNN model took a maximum time of less than 2 minutes per case compared with an average of 7 minutes by decision tree model. This performance strengthens the feasibility of CNNs to standardize the flow of work in a high-volume clinic, which contributors a more rapid decision and provides a high accuracy of diagnosis.Overall, CNN model performed better in comparison with decision tree in terms of all indicators and is, therefore, a more adequate AI solution of cancer detection on the basis of imaging in the present study.

AI Model Accuracy by Institution

Table No:2

Institution	Accuracy (%)
Aga Khan University Hospital (Karachi)	93.5
Shaukat Khanum Cancer Hospital (Lahore)	90.8
Pakistan Institute of Medical Sciences (PIMS, Islamabad)	89.6

The diagnostic accuracy of the AI model utilized in this research was found institution-wise and given in Table 2. At Aga Khan University Hospital (Karachi), the level of accuracy showed the best figure (93.5%). This high performance could probably be because of high grade imaging framework, consistency of norms, and the quality but digitized imaging records of the hospital. This will facilitate the efficiency of AI models because the variability and noise are minimal. The effectiveness of the model turn out to be strong (90.8%) at Shaukat Khanum Cancer Hospital (Lahore) but slightly lower than AKUH. This can be as a result of slight discrepancies in image resolution or procedural standardization.

Pakistan Institute of Medical Sciences (PIMS, Islamabad) had the lowest accuracy even though it is high at 89.6%. Such a result may be attributed to higher inconsistency in image quality, uneven digitization, or lagging imaging technologies, which may have interfered with one of the model capabilities to read the pattern accurately.The overall takeaway is that although the AI model was effective in all three institutions, the outcome indicates the sensitivity of the performance of AI to the infrastructure and quality of the institution data. These variations indicate that uniform imaging operation and a well-developed digital infrastructure will be needed to perform AI tools successfully in any of the healthcare environments.

Discussions

The results of this research paper prove that AI models and especially convolutional neural networks (CNNs) can be very useful in helping to detect cancer early in their development in Pakistan due to the high rate of diagnostic success, rapidity, and consistency. The CNN model performed with a sensitivity of 92.3 percent, specificity of 89.7 percent and AUC statistic of 0.94, which were comparable with other global research findings that reveal a higher or comparable accuracy rates to AI-based oncology diagnostics (Esteva et al., 2022). These findings confirm the increasingly strong evidence that AI, particularly deep learning, is able to perform as well as, or better than, a human in the detection of malignancies across the full range of imaging modality.The excellent per performance between CNNs and conventional decision tree classifier on image medical analysis emphasizes the essence of deep feature extraction on medical images. Even though decision trees are interpretable, their lower accuracy rates and AUC are indicative of its weak performance in image-based complex tasks. The results match the prior studies that prefer CNNs in the diagnostic imaging application, which include mammography (Lehman et al., 2021) and histopathology (Bulten et al., 2020).

Differences in institutional performance found in this study additionally highlight the contribution of high-quality data, and infrastructure to AI performance. Aga Khan University Hospital recorded the best results (93.5%) due to access to modern imaging technology with support of digital integration. By contrast, Shaukat Khanum and PIMS have slightly lower accuracies, which is probably the result of differences in image quality, equipment, and the manner of image digitization. Such differences reaffirm the importance of the use of standardized imaging standards with strong IT infrastructure, which can optimize the use and positive effect of AI tools, as mentioned by Wiens et al. (2021). The results of the stakeholder interviews confirmed the overall view of AI integration, including its opportunities to help in case of diagnostic delays and relieve overworked clinicians. Most of the participants considered the AI as a helpful second opinion that could be helpful in rural or high-volume environments. This belief is aligned with the opinion of past researchers on the same topic in low- and middle-income countries (LMICs), where it is believed that AI will reduce the gap in the availability of specialized radiologists and oncologists (Li et al., 2019). But the main point is that the implementation of an algorithm, in general, must be prepared organizationally, with appropriate education and culture.

In the qualitative analysis, few challenges were realized. Infrastructural constraints, such as unavailability of high-tech digital infrastructure, ageing imaging devices and absence of skilled workforce continues to pose serious challenges to the implementation of AI across the healthcare delivery in Pakistan. These difficulties are faced in the LMICs and observed in studies similar in India and sub-Saharan Africa (Akinyelu & Blignaut, 2022). In addition, ethical issues related to data privacy, transparency of the algorithms, and accountability in the institution of a potential diagnostic error were mentioned. These concerns emphasize the necessity of policy guidelines that control the practice of AI in clinical practice to safeguard patients and advise cliniciansAnother interesting discovery is the time-saving ability of AI. The CNN shortened the average time of interpreting the images by 12 minutes down to less than 2 minutes implying a high possibility of workflow acceleration. That would be especially effective in Pakistan where due to patient volume, the available resources are so limited that oncologists and radiologists have to work. Quicker diagnosis is beneficial not solely to patients but also to what is known as earlier intervention, which is key in as far as survival in cancers diagnosed at an early stage is concerned.

Although there is a good outcome of the research, there are flaws to this research. First, the study selected only three city institutions, which might not be sufficient to reflect the state of events in the smaller or rural hospitals. Second, although the AI models were tested on a variety of imaging modalities, more effort must be dedicated to check generalizability on rare malignancies or multimodal diagnostic combinations. Third, the ethical issues and the patient views were not touched upon closely and require further research. It is recommended in future research that the dataset is increased, settings are widened to rural areas, and AI should be integrated into a wider clinical workflow.On the whole, the current paper proves the ability of altering the world of cancer diagnostics in Pakistan with the AI concept. But in order to achieve this potential, large investments should be made in digital health infrastructure, the education of clinicians, and ethical governance. Artificial intelligence must remain an accessory device--not a substitute to human knowledge and expertise and the implementation of AI should be premised on patient-focused and context informed implementation strategies.

Conclusion

This research illustrates high prospects of machine learning to be applied in optimizing early diagnosis of cancer in the Pakistani health sector, especially by means of the convolutional neural networks (CNNs). AI models offer significant clinical decision support capability with a high diagnostic accuracy rate, a short reduction in interpretation time, clinically similar performance applied across a variety of imaging modalities, and can support clinical decision-making particularly in resource-poor settings. The qualitative data obtained on healthcare personnel further attest the increased interest and optimism with concerns with regards to adopting AI as a diagnostic aid instrument .Although those are encouraging outcomes, there are a number of implementation issues. Insufficient infrastructure resources, uneven digitization, the shortage of skilled workforce, as well as ethical issues, such as data protection and algorithm visibility, are some of the problems to overcome in order to ensure safe and effective integration of AI. The discrepancy in the AI performance at different institutions also indicates the necessity of harmonization to imaging approval and adoption of quality data systems. To wrap up finding clinical expertise is not needed since AI will only serve as a potent complement and can enhance diagnostic speed, accuracy, and access to care especially in overburdened environments such as Pakistan. Policymakers, hospital administrations, IT developers, and clinicians have to work synergistically to achieve significant and fair implementation. Investments in the digital infrastructure, training activities and regulatory agencies will be crucial in bringing the potential in AI into reality to drive positive changes in cancer care and patient outcomes.

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