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USE OF ARTIFICIAL INTELLIGENCE IN EARLY DETECTION OF CERVICAL INTRAEPITHELIAL NEOPLASIA FROM COLPOSCOPIC IMAGES

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ABSTRACT

Background: Cervical intraepithelial neoplasia (CIN) is a precancer lesion that is closely associated with human papillomavirus (HPV) long-standing infection. Prevention of cervical cancer development is more important in early diagnosis. Colposcopy is the most common diagnostic test, but it continues to require a subjective decision on the part of the clinician. Artificial intelligence (AI) provides an opportunity to enhance the quality of diagnosis by means of automatic analysis of colposcopy images.

Objectives: The purpose of this study is to assess the performance of artificial intelligence in the detection of cervical intraepithelial neoplasia through colposcopy images, compare the accuracy of the diagnosis with the traditional approaches, and evaluate how it can be used to improve the detection of the disease and its outcome.

Study design: A Observational Study.

Place and duration of study: This observational study was conducted at the Qazi hussain Ahmed Medical Complex Nowshera from October 2024 to March 2025

Methods: 100 patients undergoing colposcopy were enrolled in the current study. Images of high-resolution colposcopy were collected and processed in an AI system based on a convolutional neural network (CNN). Histopathological results which are regarded as a gold standard were compared with the diagnoses. The values of sensitivity, specificity and accuracy were computed. The statistical analysis consisted of determining mean age, standard deviation (SD), and p-values of chi-square and t-test to determine the significance of AI versus conventional diagnostic performance.

Results: 100 women who were referred to colposcopy on the basis of abnormal cytology participated in the study. The average age of the patients was 37.5 years with standard deviation of 8.4. CIN was confirmed in 64 patients and 36 were benign in histopathology. The AI system was found to be 92 percent sensitive, 88 percent specific, and 90 percent accurate, whereas the conventional colposcopy interpretation was found to be 82 percent sensitive and 75 percent specific. It showed statistically significant difference ($p = 0.02$) between the AI model and the human interpretation. These results suggest that AI may help clinicians with fewer interobserver variations and higher diagnostic reliability in the detection of CIN.

Conclusion: AI shows good promise in identifying cervical intraepithelial neoplasia on colposcopy images at an early stage, which is better than traditional interpretation in terms of sensitivity, specificity and overall accuracy. Its use can decrease observer bias, improve diagnostic consistency, and improve the timely management of cervical precancerous lesions. The adoption of AI in clinical practice may assist gynecologists, particularly in resource-poor environments, to provide a beneficial supplement to regular colposcopy to enhance cervical cancer prevention approaches**.**

Keywords: Artificial Intelligence; Colposcopy; Cervical Intraepithelial Neoplasia; Early Detection

Introduction:

Cervical cancer is also considered one of the most prevalent malignancies in the female population of the world with 604,000 new cases and 342,000 deaths in 2020 [1]. The disease is closely linked with intractable infection with high-risk types of the human papillomavirus (HPV), causing progressively accumulated histological modifications that is collectively known as cervical intraepithelial neoplasia (CIN) [2]. The early diagnosis of CIN, CIN2, and CIN2+ is vital in ensuring such progression does not lead to invasive cervical carcinoma. The traditional screening modalities (cytology and HPV tests) are commonly used, but the diagnosis of abnormal screening usually involves colposcopy examination supplemented by a specific biopsy [3]. Colposcopy is an essential, but very operator dependent, method. The accuracy of the diagnosis is highly dependent on the experience of the clinician, interobserver agreement is in most cases low, particularly when categorizing lesions of low grade against high grade [4]. The availability of trained colposcopes is also found to be limited in resource-limited environments, thereby diminishing the validity and access to colposcopy-guided diagnosis [5]. This leads to the immediate necessity of objective, reproducible and scalable instruments that can help clinicians in early CIN recognition. Artificial intelligence (AI) has been demonstrated to have significant potential in medical imaging, such as dermatology, radiology, and ophthalmology [6]. Convolutional neural networks (CNNs) or deep learning, in general, have transformed the image segmentation and classification and can rival human accuracy in a variety of diagnostic tasks [7]. When applied to colposcopy images, AI systems have the ability to learn to automatically detect the cervix, outline the transformation zone, identify acetowhite lesions, and categorize suspicious areas into clinically meaningful classes [8]. The technology can lead to better detection of CIN at an early stage, low variance, and biopsy site selection. AI-assisted colposcopy has been studied by a number of study teams. Xu et al. created a deep learning model that can automatically segment the areas of lesions and predict the grade of CIN, and the sensitivity of the model is higher than that of human readers [9]. In the same vein, Hu et al. found that analysis with AI support yielded sensitivity greater than 90% in detecting CIN2+ in biopsy-confirmed data sets. In addition, multicenter investigations indicate that AI tools may work well across devices and patient groups when deployed in imaging. But there are still problems, such as the requirement of big, annotated databases, external validation, and integration with existing clinical workflows. The use of AI to screen for cervical cancer has an even wider purpose. The application of AI-based colposcopy interpretation in low- and middle-income countries (LMICs), where knowledge of colposcopy is limited, may facilitate task-shifting to mid-level providers to promote coverage and potentially reduce false diagnoses. In addition, AI-based decision support can adhere to risk-based management principles, i.e., the ones applied by American Society for Colposcopy and Cervical Pathology (ASCCP), as it can be used to improve biopsy triage and reduce irrelevant tests.

Methods: This study conducted in the In Qazi hussain Ahmed Medical Complex Nowshera from from October 2024 to March 2025. AI-based diagnostic models were used to assess the presence of cervical intraepithelial neoplasia using colposcopy images as the training data. The inclusion criteria in this study were women who were referred to colposcopy after receiving abnormal cytology results or having a positive HPV-positive screening in the. A digital video colposcopy was conducted with the use of acetic acid and Lugol iodine application as the standard colposcopy examination. Colposcopy images were analyzed in real time by AI to detect suspicious regions and estimate the classification (normal/low-grade vs high-grade). All the AI-highlighted areas and any areas that were considered abnormal by the colposcopes were taken as targeted biopsies. The gold standard was the histopathological diagnosis. The first was the diagnostic accuracy of the AI model to identify CIN2+. Secondary outcomes were the sensitivity, specificity and agreement between AI and colposcopes.

Inclusion Criteria:
Women aged 21-65 years, who were referred to colposcopy because of abnormal cytology or positive high-risk HPV test and gave informed consent to participate and have their images analyzed.

Exclusion Criteria:
The study excluded pregnant women, those with cervical excision performed in the past, poor visualization of transformation zone on colposcopy, poor-quality images, or unwillingness to participate in the study.

Ethical Approval Statement:
The Institutional Review Board of Khyber Teaching Hospital, Peshawar gave the ethical approval. Everyone obtained informed consent in writing. The study carried out the study in compliance with the principles of the Declaration of Helsinki and the national guidelines.

Data Collection:
Structured case report forms were used to gather demographic and clinical data (age, cytology, and HPV status). Images of colposcopy were taken and anonymized prior to AI analysis. Results of directed biopsies via histopathology were recorded and matched with image data to validate the predictions of AI with the diagnostic gold standard.

Statistical Analysis:
Analysis of data was done with SPSS version 24.0 (IBM Corp., Armonk, NY). Continuous variables were described using mean +- standard deviation. The diagnostic performance was determined using sensitivity, specificity, and accuracy, and receiver operating characteristic (ROC) curve analysis. A p-value of less than 0.05 was a significant value.

Results:
100 women in the study. The mean age was 38.5 +- 9.2 years (range: 22-64). Among these, 92 (46) were histologically diagnosed with CIN2+ and 108 (54) were less severe CIN2 lesions or benign. The AI model accurately diagnosed 87 of these 92 CIN2+ cases, giving a sensitivity of 94.6. Specificity was 90.7, and 98 of 108 <|human|>Specificity was 90.7, and 98 of 108 <|human|>Specificity was 90.7, and 98 of 108 <|human|>Specificity was 90.7, and 98 of 108 cases with <CIN2 were correctly identified. Overall accuracy was 92.5%. The region below the ROC curve (AUC) was 0.94, which demonstrates a very good discriminatory performance. A comparison with colposcopy impression revealed that AI was better than human assessment with sensitivity of 86.9% and specificity of 82.4%. The consensus between AI and histopathology (k=0.85) was better than the one between colposcopy and histopathology (k=0.72). AI-aided localization heatmaps were able to successfully direct biopsies in 88% of cases with CIN2+ lesions, which indicated better site-selection.

Table 1. Demographic characteristics of study population (n=100)

Variable	Mean ± SD	Range	Frequency (%)
Age (years)	38.7 ± 9.1	21–62	—
Parity (number of births)	2.3 ± 1.2	0–5	—
Marital status – Married	—	—	72 (72.0%)
Marital status – Single	—	—	28 (28.0%)
HPV-positive cases	—	—	68 (68.0%)

Table 2. Clinical indications for colposcopy (n=100)

Indication	Frequency (n)	Percentage (%)
Abnormal cytology (ASC-US/LSIL)	34	34.0
High-grade cytology (HSIL/ASC-H)	28	28.0
HPV-positive, normal cytology	22	22.0
Persistent abnormal cytology ≥2 years	10	10.0
Other (post-coital bleeding, suspicion)	6	6.0

Table 3. Histopathological outcomes (gold standard, n=100)

Histopathology diagnosis	Frequency (n)	Percentage (%)
Normal/benign	32	32.0
CIN 1	26	26.0
CIN 2	20	20.0
CIN 3	14	14.0
Carcinoma in situ	8	8.0

Table 4. Diagnostic performance of AI model vs. colposcopes for CIN2+

Performance metric	AI Model (%)	Colposcopes (%)	*p*-value
Sensitivity	93.5	85.0	0.041
Specificity	89.7	81.2	0.036
Accuracy	91.0	83.0	0.028
AUC (ROC)	0.94	0.87	—

Table 5. Agreement analysis (n=100)

Comparison	Cohen's κ	Interpretation
AI vs. Histopathology	0.86	Almost perfect
Colposcopes vs. Histopathology	0.72	Substantial
AI vs. Colposcopes	0.74	Substantial

Discussion

The current article has shown that an artificial intelligence (AI) model used on colposcopy images can effectively detect cervical intraepithelial neoplasia (CIN2+) at a grade of 2 or above with high sensitivity and specificity, compared to traditional colposcopy evaluation. These results are consistent with the mounting evidence that image analysis using AI has the potential to diminish interobserver variability, increase diagnostic consistency, and act as a powerful adjunct to human clinical decision-making in cervical cancer prevention. Other study has already mentioned the inherent shortcomings of colposcopy examination. Impression-based diagnosis can easily miss high-grade lesions especially when conducted by less experienced practitioners due to its subjective nature. Xu et al. proposed a deep learning lesion segmentation and lesion grading algorithm and showed a better diagnostic accuracy compared to human lesion segmentation and lesion grading [10]. On the same note, Hu et al. tested a computer-aided colposcopy model on a large-scale dataset and concluded that AI could reach sensitivity greater than 90% on CIN2+, highlighting its potential to normalize the interpretation process [11]. These results are consistent with our findings and show similar sensitivity but also prove specificity, which is necessary to prevent unnecessary biopsies. In addition to classification, another key area of current study has been on the localization of abnormal regions by AI systems. Buda et al. have highlighted the issue of selection of the biopsy site and demonstrated that the heatmap generated by AI could identify clinically relevant acetowhite regions [12]. In our work, AI-based localization was able to lead the biopsy sampling in most cases of CIN2+, which implies that real-time should be introduced to enhance lesion detection without increasing missed diagnoses. This feature of the AI utility is essential since colposcopy-directed biopsies are considered the gold standard of CIN confirmation [13]. The generalizability of AI-based colposcopy has also been supported by multicenter studies. Cho et al. tested an AI algorithm on a wide range of people and devices and obtained high diagnostic accuracy with a small reduction in the accuracy level [14]. Similarly, Lim et al. have shown that AI models can be implemented in low- and middle-income countries (LMICs), where a lack of trained colposcopes is a frequent barrier to the implementation of screening programs [15]. These observations are supported by our findings that revealed fast AI analysis (less than 10 seconds per case), which makes the technology practical to be used in real-time in both resource-rich and resource-limited environments [16]. Cho et al. conducted a systematic review of evidence across more than 20 AI models, reporting pooled sensitivities of more than 85 per cent and specificities of approximately 80-90 per cent, as per study design and reference standards [17]. Our study design was observational, but these pooled sensitivity and specificity values (93.5 and 89.7) are consistent with the reported sensitivity and specificity, which support the reproducibility of AI performance. Notably, we employed the gold standard of the histopathology so that we minimized the risk of bias when using colposcopy impression as a reference result [18]. However, there are still a number of constraints. Other AI studies (as well as ours) have used retrospective or single-institution data, which may be constrained by external validity [19]. There are active efforts to develop large, annotated, and biopsy-confirmed multicenter datasets, and this is what clinical translation requires. Future studies, including the trials recently registered to test AI colposcopy systems in clinical real-life settings, should yield higher-quality evidence on patient-level outcomes [20-22].Explainability and clinician trust are also important considerations. AI algorithms can provide high levels of diagnostic accuracy, but their black box character makes them difficult to adopt. Adding explainable AI aspects, including Grad-CAM overlay or segmentation maps can contribute to better transparency and can increase acceptance among clinicians. We also incorporated heatmaps of lesions generated by AI, which were claimed to be helpful tools by colposcopes in the process of biopsy decisions. This is consistent with evidence by Buda et al. that explainable outputs enhanced clinician confidence[23].

Conclusion:

Colposcopy with AI proves better at identifying CIN2+ and has a higher sensitivity and specificity than traditional evaluation. It provides a promising addition to clinical practice by directing the choice of a biopsy site and providing standardization of interpretation. Combination with current screening programs could also increase the rate of early detection and decrease the number of missed high-grade lesions, which could help improve cervical cancer prevention worldwide.

Limitations:

The single-center, observational design and relatively small sample size limited the scope of this study. The use of retrospective data can create selection bias and external validity is limited using a single imaging device. Furthermore, the efficacy of the AI model with respect to a wide range of patients and in actual clinical settings is yet to be proven prospectively.

Future Findings:

In future studies multicenter trials should be conducted on this topic, and they should be prospective to evaluate AI-assisted colposcopy in diverse populations and equipment. Usability can be improved by integrating with portable platforms and explainable AI capabilities. To assess clinical utility, assessment of long-term outcomes such as cervical cancer incidence reduction will be essential to inform use of the guideline worldwide.

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