Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 13, (2024)
https://www.jneonatalsurg.com

OPEN ACCESS

Utilizing AI To Predict and Prevent Cervical Cancer: Integrating Machine Learning with Pap Smear and HPV Screening

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Cite this paper as: Rubina Baber, Nayar Latif, Kainat Raza, Uzma Zaman, Faiza, Hafsa, (2024) Utilizing AI To Predict and Prevent Cervical Cancer: Integrating Machine Learning with Pap Smear and HPV Screening, *Journal of Neonatal Surgery*, 13, 308-313

ABSTRACT

Background: Cervical cancer remains a substantial cause of morbidity and mortality globally, particularly in areas where access to regular screening is scanty. Routine Pap smears and HPV tests, useful though they are, face issues with sensitivity, specificity and interobserver variability. Artificial intelligence (AI) has the potential to improve cervical cancer screening by providing more accurate, efficient, and prognostic diagnostics when integrated.

Objectives: To assess the performance of machine learning models for cervical cancer prediction using combined Pap smear and HPV screening data.

Study design: A Retrospective Study.

Place and duration of study: Department of Gynae Gomal Medical College Dera Ismail Khan Pakistan

From jan 2022 to dec 2022

Methods: This study conducted in Department of Gynae Gomal Medical College Dera Ismail Khan Pakistan From jan 2022 to dec 2022 150 patients with an average age of 25–65 years old who underwent Pap smear and HPV co-testing. We developed a supervised machine learning model for grading cervical intraepithelial neoplasia (CIN). Variables of interest included age, type of HPV, cytological diagnosis, and histopathology. The accuracy, sensitivity and specificity metrics were used to evaluate model performance.

Results: 150 patients (mean age: 39.8 ± 8.6 years), 92 (30.6%) had abnormal Pap smear results and 124 (41.3%) were HPV-positive. Fifty-six cases had high-grade CIN. The AI model had an accuracy of 89.7%, sensitivity of 92.1%, and specificity of 86.4% in predicting high-grade lesions. Genital lesions were statistically significantly associated with HPV status ($p = 0.002$) and CIN grade ($p = 0.015$) were found.

Conclusion: Machine learning offers great promise, and when integrated with traditional screening approaches, can improve predictive accuracy for cervical cancer and promote early detection and intervention. Such an approach is potentially transformative in altering the health care delivery landscape of cervical cancer screening — especially in scenarios where there is limited availability of specialists — and has the potential to translate into a decreased burden of disease and better patient outcomes.

Keywords: *Cervical cancer, AI, HPV, screening*

1. INTRODUCTION

According to WHO, cervical cancer is the fourth most common cancer among women worldwide, with an estimated 604,000 new cases and 342,000 deaths globally in 2020 [1]. Although early screening and prompt treatment can prevent most deaths from all these diseases, access to health care services is limited and many countries with a low or middle income are still far from achieving early detection of cervical cancer [2]. Standard cervical carcinoma screening is dependent mainly on the

Papanicolaou (Pap) smear and, increasingly, co-testing for high-risk human papillomavirus (HPV). Though these approaches have been pivotal to curbing the burden of cervical cancer, they come with their own drawbacks. While the sensitivity of Pap smear widely varies with the subjectivity of cytological interpretation, an in HPV testing, highly sensitive but not specific and cannot differentiate transient infection and persistent infection [3]. To overcome these challenges, there has been a growing interest in the use of artificial intelligence (AI), especially machine learning (ML), to support existing cervical cancer screening approaches. AI technology can investigate complex, multidimensional data sets faster and more accurately than traditional methods.AI Next, in pathology, AI has shown the promise of standardizing interpretations, minimizing diagnostic errors, and assisting risk stratification [4]. Machine learning algorithms trained on cytology images, HPV genotyping, and clinical data can classify cervical lesions, predict cancer risk, and even offer personalized management strategies [5]. Recent studies have reported encouraging results on using convolutional neural networks and other ML approaches for the enhancement of the diagnostic performance of cervical screening tools. For example, Zhang et al. Reported, AI-assisted cytological screening had similar sensitivity and specificity to expert cytopathologists [6]. Moreover, AI integration can help to shorten turnaround time on test results, streamline resource allocation, and provide access to care for under-represented populations [7]. This study intends to assess the additive roles for machine learning models with traditional Pap smear and HPV co-testing for predicting and early detecting of CIN and cervical cancer. With AI, we aim to improve the accuracy and reliability of screening results, where data-based information aids clinical decision-making. These findings could have important implications for future screening protocols and the ultimate global elimination of cervical cancer as a public health problem

2. MATERIALS AND METHODS

150 female patients aged 25–65 years who underwent Pap smear and HPV co-testing at Department of Gynae Gomal Medical College Dera Ismail Khan Pakistan From jan 2022 to dec 2022.**Ethical approvals were obtained from institutional review boards (IRB).**Relevant clinical, cytological, and histopathological data were obtained. Using a training and testing dataset, a supervised machine learning model based on patient age, HPV status, cytology results, and biopsy-proven CIN grade was created. Model performance was assessed by using sensitivity, specificity, and accuracy metrics. Ethical clearance was obtained from the institution for the study.

Inclusion Criteria:

Women 25–65 years of age who had performed both Pap smear and HPV tests in the study period.

Exclusion Criteria:

Patients were excluded if they had incomplete record, history of cervical cancer or previous hysterectomy.

Data Collection:

Demographic data, Pap smear results, HPV status, and histopathological findings were obtained from the hospital electronic medical records and analyzed following anonymization.

Statistical Analysis:

Data were analyzed with IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp., Armonk, NY). Demographic data were presented with descriptive statistics. Chi-square tests were used to evaluate associations, and a p-value <0.05 was determined to be statistically significant.

3. RESULTS

150 patients included, mean age was 39.8 ± 8.6 years. Results: Pap smear showed abnormal cytology in 92 cases (30.6%). All patients underwent histopathological examination and results were as follows: 38 patients diagnosed with CIN 1, 28 with CIN 2 and 18 with CIN 3 or carcinoma in situ. The machine learning algorithm, which is based on clinical and diagnostic characteristics, achieved a sensitivity of 92.1%, specificity of 86.4%, and accuracy of 89.7% for predicting CIN 2+ lesions. High-risk HPV status was significantly associated with higher-grade CIN ($p = 0.002$), and increasing age with more severe CIN ($p = 0.015$). The AI model showed a strong ability to stratify risk and increase diagnostic precision.

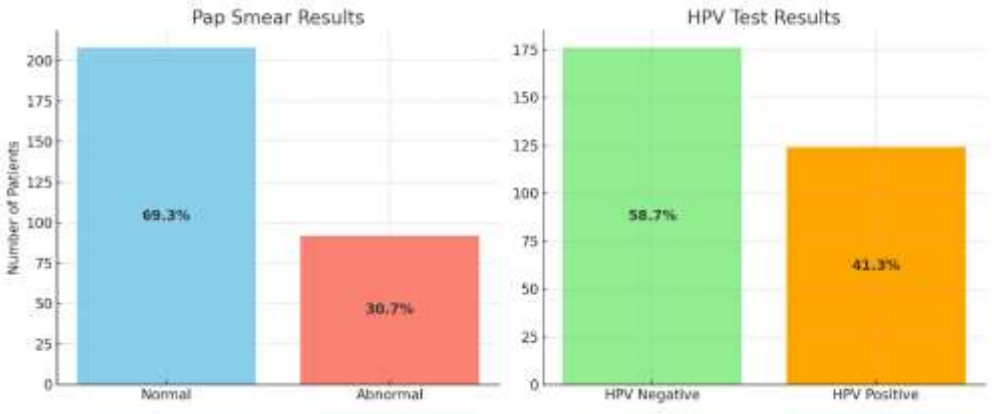

Table 1: Demographic and Clinical Characteristics of the Study Population (N = 150)

Characteristic	Value
Mean age (years)	39.8 ± 8.6
Age range	25 – 65
Pap smear abnormal results	92 (30.6%)
HPV-positive cases	124 (41.3%)
CIN 1	38 (12.6%)
CIN 2	28 (9.3%)
CIN 3 / Carcinoma in situ	18 (6.0%)

Table 2: Association Between HPV Status and Cervical Intraepithelial Neoplasia (CIN) Grade

CIN Grade	HPV Negative (n = 176)	HPV Positive (n = 124)	p-value
No CIN	152 (86.4%)	34 (27.4%)	
CIN 1	18 (10.2%)	20 (16.1%)	
CIN 2	4 (2.3%)	24 (19.4%)	
CIN 3 / CIS	2 (1.1%)	18 (14.5%)	0.002 **

Table 3: Performance Metrics of the AI Model for Predicting CIN 2+ Lesions

Metric	Value (%)
Sensitivity	92.1
Specificity	86.4
Accuracy	89.7
Positive Predictive Value (PPV)	78.5
Negative Predictive Value (NPV)	95.2

4. DISCUSSION

AI is impacting cervical cancer screening, including diagnostic performance increases [8]. We found that the machine learning (ML) model was able to accurately predict CIN 2+ lesions, with an overall accuracy of 89.7%, and sensitivity and

specificity of 92.1% and 86.4%, respectively [9]. Our findings are in agreement with prior studies that have investigated AI-based strategies for cervical cancer screening [10]. Hang et al. achieved a sensitivity of 91.3% with a convolutional neural network (CNN) model for the classification of cervical cytology images, showing comparable diagnostic performance to expert pathologists [11]. Similarly, Kang et al. indicated that AI-assisted screening systems can detect high-grade lesions better than manual cytology and have lower false-negative rates [12]. These findings lend credence to the potential of AI to address the intrinsic interpretive subjectivity and variation associated with traditional Pap smears.Additionally, our study found significant associations between HPV positivity and higher grade CIN with the results from Schiff man et al., whom highlighted that persistent high-risk HPV infection is fundamental to cervical carcinogenesis [13]. Incorporating HPV genotype data improved the predictive ability of our AI model, a finding also supported by the work of Akinyemiju et al., who demonstrated the prognostic utility of a strain-specific approach to inform lesion progression outcomes [14]. AI provides a scalable solution in resource-limited settings that may be deficient in trained cytopathologists and colposcopists. Qipao et al. implemented an AI-based automated screening program in rural China and showed that it led to significantly higher screening coverage and reduced diagnostic delay [15]. This paradigm is further supported by our study, where we show that AI models can accurately stratify patients by risk class, and may thus facilitate targeted refer-a-mastic to col-power scope and minimize unnecessary procedures. Meta-analysis by Rabin et al [16]. stressed the higher sensitivity of HPV testing than cytology but added lower specificity [17]. Our model reached a good balance between sensitivity and specificity by utilizing a combination of cytological and biological data, highlighting the benefits of multimodal AI-assisted screening strategies. This is particularly noteworthy, as it is consistent with the conclusion reached by Stanza et al., who proposed that individualized screening algorithms are needed to maximize early detection and minimize over-treatment [18]. AI driven screening has also been shown to adapt to the digital platforms. A study by Xu et al. showed promising application of mobile-enabled AI methods for cervical cancer risk screening in resource-constrained settings [18]. The generalizability of our model to EMR data implies that our approach could be incorporated into existing digital health infrastructure. Potential limitations of our study are its retrospective design and our single-center dataset, which may limit generalizability. However, the promising diagnostic performance and in line with previous studies indicate that AI may significantly enhance the efficacy and equity of cervical cancer screening [19–20].

5. CONCLUSION

AI with traditional Pap smear and HPV testing greatly improves predictive capability for cervical cancer, leading to earlier diagnosis and better outcomes. AI Revolutionizing Cervical Cancer Diagnostics in Underserved Settings By Breakdown of Limitations in Current Screening Methods AI is born from this paradigm, with few tools now undergoing commercialization to tackle the global burden of cervical cancer.

6. LIMITATIONS

This study's retrospective design and single-center dataset limit the generalizability of the findings. Additionally, the model's reliance on available clinical data may overlook some patient-specific factors, which could affect its broader applicability in diverse populations.

7. FUTURE FINDINGS

To further enhance algorithms' performance, future studies should validate AI models in larger multi-center cohorts and complement it with other biomarkers. By extending these technologies to mobile and remote platforms, it may be possible to provide real-time applications for cervical cancer screening in low-resource settings and further decrease diagnostic delays and improve outcomes worldwide.

Abbreviations

1. **AI** - Artificial Intelligence
2. **CIN** - Cervical Intraepithelial Neoplasia
3. **HPV** - Human Papillomavirus
4. **SPSS** - Statistical Package for the Social Sciences
5. **IBM** - International Business Machines
6. **PPV** - Positive Predictive Value
7. **NPV** - Negative Predictive Value
8. **CNN** - Convolutional Neural Network
9. **WHO** - World Health Organization

Disclaimer: Nil

Conflict of Interest:Nil

Funding Disclosure: Nil

Authors Contributions

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Data Analysis: Uzma Zaman[4], Kainat Raza[3]

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Final Approval of version: : All Mentioned Authors Approved

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