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**Original Research Article**

# Current Status of Machine Learning and Artificial Intelligence in Cervical Cancer Screening and Diagnosis: A Systematic Review

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**Abstract:** ***Background***: Cervical cancer poses a substantial global health challenge, predominantly affecting underprivileged countries. The limitations of current screening methods, such as cytology and visual examination, underscore the need for improved techniques. Artificial intelligence (AI) and machine learning (ML), particularly convolutional neural networks, offer promising solutions in this regard. ***Methodology***: Fifteen studies meeting the inclusion criteria were examined. The PRISMA criteria guided the exploration of cervical cancer screening studies employing AI, ML, and deep learning on PubMed/MEDLINE and Google Scholar. The search focused on "artificial intelligence" and "Pap smear." The investigation specifically delves into English-language studies post-2019 that pertain to the machine learning and deep learning classification of cervical cancer using mobile devices. Histology, animal research, and pre-2019 investigations are excluded. Titles and abstracts were carefully reviewed for any discrepancies and subsequently discussed. The process of data extraction involved compiling information from the selected articles. ***Result***: The systematic review investigates the impact of AI and ML on cervical cancer detection, screening, and diagnosis. Our review reveals enhanced accuracy and efficiency in innovative technologies such as CytoBrain and computer-aided diagnostic systems employing Compact VGG and ResNet101. ML techniques like logistic regression, MLP, SVM, KNN, and naive Bayes prove beneficial for managing complex datasets, particularly when combined with class-balancing procedures. The promising aspects include the application of deep learning for automation and AI-assisted digital microscopy. These findings signify a transformative shift in cervical cancer screening, underscoring the potential of ML and AI technologies to elevate diagnostic accuracy and accessibility. ***Conclusion***: Our study demonstrates advancements in both accuracy and responsiveness. Despite recognizing scientific and ethical considerations, the study underscores the potential of AI to enhance cervical cancer care. This systematic review advocates for policymakers and healthcare practitioners to use ongoing research for informed decision-making in this rapidly evolving field.

**Keywords:** Cervical Cancer, Artificial Intelligence, Machine Learning, Screening, AI, Challenges.



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## 1. INTRODUCTION

Cervical cancer is a significant global health issue, causing the fourth-highest number of cancer-related fatalities worldwide. It mostly affects impoverished nations, accounting for 70% of all cases [1]. Cervical cancer is a significant challenge, particularly in low- and middle-income countries (LMICs). The global incidence of cervical cancer in 2020 reached 604,000, positioning it as the fourth most prevalent ailment among women. The World Health Organisation (WHO) reported that almost 90% of the 342,000 fatalities caused by cervical cancer took place in countries with low and intermediate incomes in the year 2023. The incidence of cervical cancer is much higher among women residing in low- and middle-income countries (LMICs) as a result of limited availability of early detection, poor treatment options, and insufficient screening initiatives [2, 3]. The need for effective preventative and early detection strategies is underscored by the causal link between high-risk strains of human papillomavirus (HPV) and persistent infection, which is recognized as a leading cause of cervical cancer [1].

The current main and secondary preventative measures, and conventional screening methods, which rely on cervical-vaginal cytology and viral genotyping testing, have shown varying levels of accuracy in detecting and identifying cervical cancer. In addition, the implementation is hindered by long durations of delivering results [4-6]. Image-based diagnostic procedures, such as colposcopy, possess limitations as they need specialized training and rely on subjective expertise. The gold standard for diagnosis is colposcopy, which may be followed by a biopsy if necessary. However, its usefulness is hindered by its poor specificity and the variability observed between different observers and within the same observer [1]. Integrating artificial intelligence (AI) with image-based diagnostic methods might potentially address the limitations of traditional methodologies and enable prompt, precise, and efficient diagnosis [1-6]. These technologies, known as cognitive computing systems, enable autonomous decision-making and adaptation to the environment by simulating human cognitive processes [7]. The application of machine learning (ML) and deep learning (DL) techniques, such as convolutional neural networks (CNN), might potentially revolutionize cervical cancer screening by enabling automatic classification of images [1-7]. This systematic review was performed following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines to provide a comprehensive summary of the existing data on the precision of machine learning techniques in detecting cervical cancer by analyzing cervical images [8]. AI has demonstrated capabilities in identifying dermatological, oncological, and gynecological tumors [9-11]. It can recognize, categorize, and extract attributes from photos, potentially revolutionizing cervical cancer diagnosis [12]. AI's impact on pathology and imaging diagnostics is notable but is seldom utilized in large-scale displays [13, 14]. This systematic review aims to assess AI technologies for cervical cancer and pre-cancerous lesions, connecting technology with practice.

## 2. MATERIALS AND METHODS

### 2.1 Database Search:

We conducted a systematic literature search following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria. The search encompassed three major databases: PubMed/MEDLINE and Google Scholar. Employing the methodological framework proposed by Arksey and O'Malley, a scoping review was conducted.

Our comprehensive search involved PubMed AND Google Scholar, employing English-language search phrases related to cervical cancer AND (artificial intelligence (AI) OR machine learning (ML) OR deep learning (DL)). The search encompassed various terms associated with screening, prediction, AND diagnosis, including "artificial intelligence," "cervical cancer," "cervical intraepithelial neoplasia," and "Pap smear." Additional terms included "early screening," "risk assessment," "sensitivity," "specificity," "imaging techniques," "portable electronics," "high-grade intraepithelial squamous lesion (HSIL)," "intraepithelial squamous lesion of low grade (LSIL)," AND "cervical neoplasms in women."

### 2.2 Inclusion and Exclusion Criteria

We focused on recent studies related to cervical cancer screening, diagnosis, and prediction, limited to publications in English and those released after the year 2019. The scope included original quantitative research articles and conference abstracts that specifically addressed the application of ML and DL in the classification of cervical images obtained through mobile devices, cervicography, or digital colposcopy. Exclusions comprised studies on image segmentation, histology, histopathology, review papers, theses, patents, editorials, letters to the editor, full-text articles, research involving animals, genomic and molecular analyses, nucleus segmentation, biomarkers, chromosomal changes, optoelectronic sensors, spectroscopy, mathematical models, and predictions related to cervical cancer. Additionally, articles that did not address the research question and research conducted before the year 2019 were also excluded.

### 2.3. Study Selection

The eligibility of articles was assessed by screening their titles and abstracts, followed by a thorough review of the complete texts. Any discrepancies were resolved through discussions.

### 2.4. Data Synthesis and Extraction

Data Extraction: A subset of the chosen publications was subjected to detailed information retrieval by three independent reviewers. This involved collecting specifics such as authors, publication year, sample size, methodologies, and datasets, utilizing a pre-piloted standardized form. Subsequently, an evidence matrix was generated using Microsoft Excel 2016, incorporating details like the nation, journal, and year of publication.

## 3. RESULTS

Following the methodology outlined by the Preferred Reporting Items for Systematic Reviews (PRISMA), our extensive literature search yielded 1,284 records from relevant databases. After a meticulous screening process, removing duplicates, and methodical assessment of 1,014 records, 895 were deemed unsuitable for various reasons. These reasons included publications preceding 2019 (61 records), incomplete or non-English articles (11 records), and studies not directly addressing the study topic (29 records). Subsequently, after evaluating 119 publications for eligibility, a final set of 15 research articles were included in this systematic review. The figure illustrates the PRISMA Flow Chart detailing the process of selecting studies.

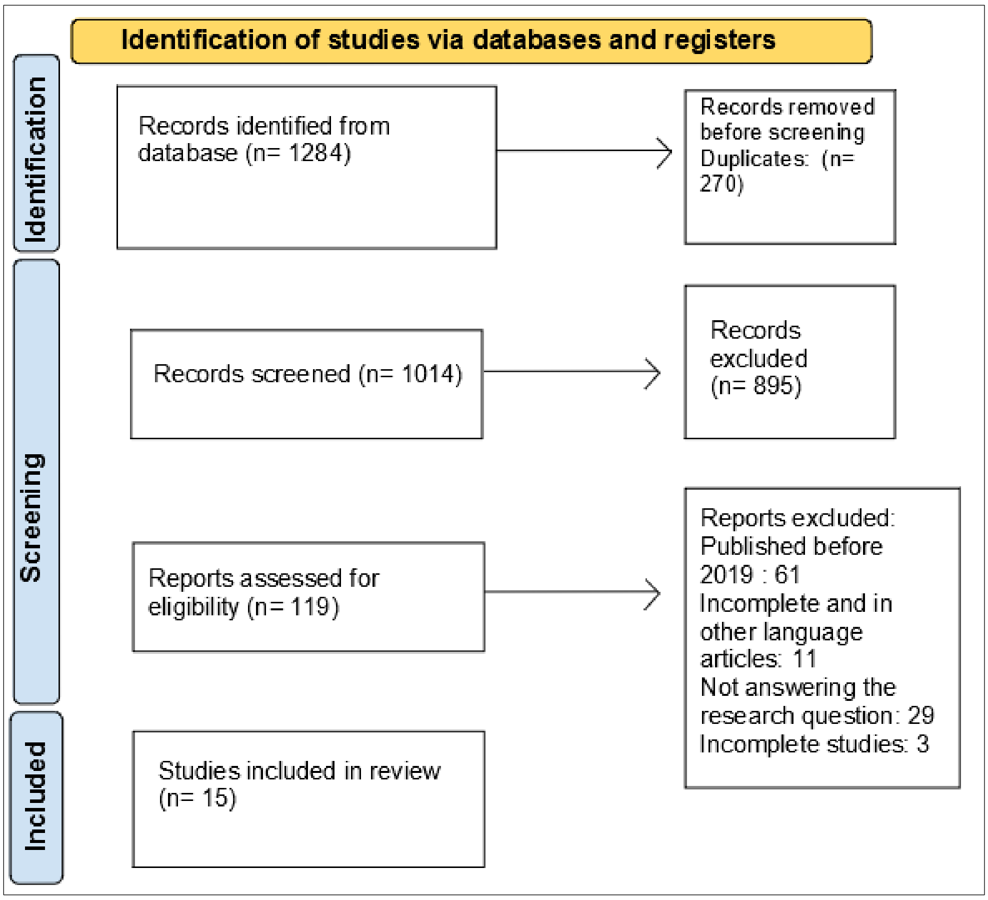


**Figure 1: PRISMA Flowchart of the Study Selection Process**

The table provides information on the studies incorporated into the systematic review.

**Table 1: Studies Included and Data Extraction Summary**

| Authors | Participants | Study Design | Objective | Summary |
|---|---|---|---|---|
| Bao *et al.*, 2020 [13]. | 7031 | Prospective Cohort study | The study employs AI-assisted cytology for cervical cancer screening, comparing results with cytologists' assessments to identify abnormal slides. Additionally, AI is used in | The study found a high agreement rate of 94.7% and a kappa value of 0.92 between AI-assisted cytology and manual reading. Both methods showed increased detection of CIN2+ with |

| Authors | Participants | Study Design | Objective | Summary |
|---|---|---|---|---|
| | | | digital microscopy for Papanicolaou tests. Its main objective is to assess the system's effectiveness in detecting abnormal cervical findings, comparing results with manual reading to evaluate CIN2+ occurrence confirmed through histological examination. | more severe cytology abnormalities. The AI system effectively filtered out typical cytology, improving sensitivity while maintaining specificity similar to manual reading. Specifically, it showed higher sensitivity in detecting CIN2+ in ASC-H or HSIL cases. |
| Holmstrom *et al*., 2021 [14]. | 740 | Diagnostic Study | The study utilizes AI for cervical cancer screening, comparing results with cytologists and employing AI in digital microscopy for Papanicolaou tests. It suggests AI-supported digital microscopy for Papanicolaou tests in resource-limited settings, emphasizing robust sensitivity for atypia and higher specificity for high-grade lesions. AI integration in digital microscopy holds promise for identifying abnormal cervical smears in rural clinics. | Sensitivity for atypia: 96-100%, high-grade lesion accuracy: 93-99%, low-grade lesion specificity: 82-86%. Receiver Operating Characteristic (ROC) curve areas: digital slides 0.94, traditional slides 0.96. Negative predictive values: 99-100%. Inter-rater agreement: digital slides $\kappa$ = 0.72, analog slides $\kappa$ = 0.36. |
| Chen *et al*., 2021 [15]. | 2312 | Developmental and Evaluative Study | The CytoBrain AI system, comprising the Cell Classification and Visualized Human-Aided Diagnosis modules, aims to evaluate its efficiency, particularly focusing on Compact VGG's (Compact Visual Geometry Group) performance in time and classification accuracy using a dataset of positive, negative, and irrelevant cell images. | Demonstrating significant efficiency in both time and classification accuracy. |
| Alquran *et al*., 2022 [16]. | - | Diagnostic accuracy study | The main intervention utilizes ResNet101 (Residual Network 101) for feature extraction, SVM (Support Vector Machine) for classification into seven abnormality types, and PCA (Principal Component Analysis) for feature reduction in a computer-aided diagnostic method for pap smear images. | The computer scoring method for automated Pap smear image analysis achieves high accuracy and sensitivity, ranging from 89.9% to 100%, in distinguishing normal and abnormal cases. PCA reduces features, enhancing specific classifications, while the system's speed and precision enable image analysis in less than one second. These findings suggest its potential as a reliable diagnostic tool in hospitals, addressing |

| Authors | Participants | Study Design | Objective | Summary |
|---|---|---|---|---|
| | | | | challenges in computer-aided diagnostics. |
| Glučina *et al*., 2023 [17]. | 859 | Observational and Retrospective study | Cervical cancer screening datasets are balanced using Random Oversampling, Adaptive Synthetic Sampling Approach for Imbalanced Learning (ADASYN), and Synthetic Minority Over-sampling Technique (SMOTE) techniques. Logistic regression, Multilayer Perceptron (MLP), Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and Naive Bayes algorithms enhance classification and generalization for Hinselmann, cytology, and biopsy data. Performance metrics are evaluated for each output variable, including Hinselmann, Schiller, cytology, and biopsy, with and without class balancing strategies. | The study finds that combining MLP and KNN with oversampling techniques optimizes performance. Integration of AI, ML, and class balancing significantly improves screening performance. The authors suggest developing an initial screening method using a questionnaire and AI algorithm, highlighting AI and ML's potential in enhancing cervical cancer screening. |
| Wentzensen *et al*., 2021 [18]. | 602 | Population based study | The study creates and tests a cloud-based whole slide imaging platform, analyzing p16/Ki-67 dual-stained slides with a deep-learning classifier trained on biopsy-based gold standards. It compares this platform with standard Pap and manual digital microscopy (DS) methods for epidemiological research on cervical and anal precancers, showing decreased positive rates, improved specificity, and reduced referrals for colposcopy with the AI-based DS. | The Biopsy Study shows that using AI for cervical cancer assessment removes subjectivity, ensuring consistent quality for healthcare providers and patients. This reduces the need for colposcopies, especially in vaccinated populations. AI's cloud-based nature enhances global accessibility. Overall, AI offers automation, objectivity, and significantly fewer unnecessary colposcopies compared to traditional methods. |
| Park *et al*., 2021 [19]. | 4119 | Comparative study | Comparing Machine Learning (ML) models, namely Extreme Gradient Boosting (XGB), Support Vector Machine (SVM), and Random Forest (RF), to Deep Learning (DL) model Residual Network-50 (ResNet-50) for detecting cervical cancer in cervicography images. | ResNet-50 surpasses traditional ML models (XGB, SVM, RF) in detecting cervical cancer from cervicography images, suggesting its potential for more accurate diagnoses. |

| Authors | Participants | Study Design | Objective | Summary |
|---|---|---|---|---|
| Mehmood *et al.*, 2021 [20]. | 858 | Observational study | CervDetect, a machine learning algorithm, assesses cervical cancer detection accuracy, along with mean squared error (MSE), false positive rate (FPR), and false negative rate (FNR). | CervDetect achieved a remarkable 93.6% accuracy, surpassing leading research in the field. It emphasizes early cervical cancer screening and proposes a hybrid approach combining random forest and shallow neural networks. |
| Tanimu *et al.*, 2021 [21]. | N/A | Predictive Modeling | The Decision Tree (DT) classification algorithm is employed for the prognostication of cervical cancer prognosis. | The study developed a predictive model for cervical cancer outcomes using a Decision Tree (DT) algorithm and advanced machine learning techniques, including Recursive Feature Elimination (RFE). The model achieved impressive accuracy (98%), sensitivity (100%), and specificity (97%) rates with Synthetic Minority Over-sampling Technique combined with Tomek links (SMOTE Tomek) implementation. It highlighted superiority over recent alternatives, suggesting further exploration with larger datasets. Additionally, it introduced innovative machine learning techniques and advocated for thorough scrutiny, exploring alternative feature selection methods like Least Absolute Shrinkage and Selection Operator (LASSO), while addressing early-stage forecasting challenges. |
| Elakkiya *et al.*, 2021 [22]. | 1993 | Experimental study | Automating cervical cancer screening via digital colposcopy images and Faster Region-Based Convolutional Neural Network (FR-CNN) for hierarchical multiclass categorization of three distinct lesion categories, prioritizing high accuracy. | FSOD-GAN technique demonstrated a diagnostic accuracy of 99% in identifying the stages of cervical cancer. |
| Attallah *et al.*, 2023 [23]. | N/A | Hybrid Computer -Aided Diagnostic (CAD) System | An AI-based computer-aided design (CAD) system for diagnosing cervical cancer using lightweight CNN models. | The proposed Computer-Aided Diagnosis (CAD) model aims to enhance cervical cancer diagnosis precision by incorporating features from diverse |

| Authors | Participants | Study Design | Objective | Summary |
|---|---|---|---|---|
| | | | | domains, achieving 100% accuracy with lightweight Convolutional Neural Network (CNN) models. This hybrid system integrates 35 primary components and quartic Support Vector Machines (SVM), showcasing the effectiveness of blending deep learning with manually crafted descriptors. The research underscores the importance of a hybrid approach for accurate cervical cancer identification, leveraging comprehensive features from CNNs with diverse topologies. |
| Alsmariy *et al*., 2020 [24]. | N/A | Utilization of a machine learning methodology to construct a prognostic model | Enhanced accuracy, sensitivity, and Receiver Operating Characteristic Area Under the Curve (ROC AUC) values for all target variables in cervical cancer diagnosis. | The study used machine learning techniques like a voting classifier, SMOTE, and PCA to build a predictive model for cervical cancer diagnosis. It improved accuracy, sensitivity, and ROC_AUC values across all variables. The SMOTE-voting model notably boosted accuracy (0.93% to 5.13%), sensitivity (39.26% to 46.97%), and PPA ratios (2% to 29%). PCA reduced computational time, enhancing efficiency. These models outperformed prior research in cervical cancer identification. |
| Chaudhuri *et al*., 2021 [25]. | N/A | Not Mentioned | Cervical cancer prediction with a machine learning mode | The study introduces a novel approach for early cervical cancer diagnosis using a Genetic Algorithm (GA) for feature selection and a stacked classification model. Evaluating various data mining models (Logistic Regression (LR), Naive Bayes (NB), Support Vector Machine (SVM), Extra Trees (ET), Random Forest (RF), Gradient Boosting (GDB)), the proposed ensemble model achieves over 100% classification accuracy, surpassing prior research. It enhances performance metrics and highlights the |

| Authors | Participants | Study Design | Objective | Summary |
|---|---|---|---|---|
| | | | | potential for swift and cost-effective prediction based on lifestyle characteristics and medical records. The study underscores the algorithm's ability to identify relevant features and address bias through iterative methods. |
| Parikh *et al*., 2019 [26]. | N/A | Retrospective Study | Forecasting the occurrence of cervical cancer using many factors | The study aimed to detect cancer in patients using machine learning algorithms. Initially, data bias was detected in the dataset of 898 newly diagnosed cases in Australia in 2014, which was resolved through appropriate procedures. Fine-tuning of three models revealed the k-nearest-neighbor model's superior accuracy, precision, recall, and AUC value. Additionally, the study hinted at a potential correlation between the herpes virus and cancer cell suppression, warranting further scientific investigation. |
| Ali *et al*., 2021 [27]. | N/A | Machine Learning Analysis | Utilizing machine learning techniques for early diagnosis of cervical cancer | The project aimed to develop efficient machine learning models for early cervical cancer detection, observing strong performance from Random Tree, Random Forest, and Instance-Based K-nearest neighbor algorithms. Feature transformation and selection methods were employed, highlighting the significance of system design and tuning. Results indicate machine learning's potential to accurately identify cervical cancer in its early stages using clinical data. |

The reviewed studies identify key insights, illustrating the successful development and evaluation of AI-based systems for cervical cancer detection. For instance, Chen's CytoBrain system employs deep learning technology, specifically Compact VGG, achieving notable efficiency in terms of both time and classification accuracy [15]. Similarly, Alquran presents a computer-aided diagnosis system utilizing ResNet101 and SVM classifiers, demonstrating exceptional accuracy and sensitivity in distinguishing between normal and abnormal cases [16]. Glučina *et al*., employ various class balancing strategies and machine learning algorithms, such as logistic regression, MLP, SVM, KNN, and naive Bayes, demonstrating enhanced performance in classification and generalization, especially with the integration of MLP with KNN [17].

Furthermore, the incorporation of AI into extensive cervical cancer screening initiatives shows promising outcomes [13]. AI-enhanced cytology systems exhibit strong agreement with manual interpretation, improving the accuracy of diagnosing cervical intraepithelial neoplasia grade 2 or worse (CIN2+), increasing sensitivity while maintaining specificity.

The review accentuates the importance of employing deep learning-based automation in cervical cancer detection. A cloud-based software utilizing a deep-learning classifier for dual-stain cytology demonstrates improved specificity rates and reduced referrals for colposcopy, indicating a move toward more impartial and effective screening techniques [18]. Additionally, the integration of AI into digital microscopy, particularly in resource-limited settings, proves to be a viable option [14]. AI-assisted digital microscopy accurately detects abnormal cervical smears, offering potential solutions for regions with constrained resources.

## 4. DISCUSSION

The advancements in machine learning (ML) and artificial intelligence (AI) have significantly impacted cervical cancer screening and diagnosis. The CytoBrain AI system utilizes the CompactVGG1 model for precise segmentation and categorization of cervical cells [15]. Another study addresses unbalanced datasets by introducing a screening approach incorporating a questionnaire and AI algorithms [17]. Additionally, a computer-aided diagnostic approach using ResNet101 and SVM classifiers demonstrates high accuracy in another study [16].

The effectiveness of an AI-supported cytology system in the initial screening of cervical cancer is evident in a study with encouraging outcomes [13]. The application of deep-learning-driven automation in dual-stain cytology reduces unnecessary colposcopies [18]. AI in digital microscopy for Papanicolaou tests shows promise in resource-limited settings [14]. A comparative analysis between ResNet-50 and conventional models emphasizes the improved diagnostic accuracy of ResNet-50 in cervicography photographs [19]. CervDetect demonstrates remarkable accuracy at 93.6%, emphasizing the importance of early screening [20]. A prediction model based on Decision Trees achieves an impressive accuracy of 98% in forecasting cervical cancer outcomes in another study [21].

The utilization of Fully Supervised One-Class Deep Generative Adversarial Network (FSOD-GAN) automates cervical cancer screening with a diagnostic accuracy rate of 99% [22]. Attallah develops a computer-aided design (CAD) system using advanced deep-learning techniques, achieving flawless accuracy by incorporating characteristics from multiple domains [23]. Researchers employ various machine learning methods, showcasing efficacy in constructing a prognostic model for cervical cancer, with a classification accuracy exceeding 100% [24, 25]. A retrospective study using a k-nearest-neighbor model predicts the probability of cervical cancer, addressing data bias [26]. Ali *et al*., investigate the effectiveness of machine learning techniques, specifically Random Tree, Random Forest, and Instance-Based K-nearest neighbor algorithms, in early diagnosis through statistical analysis [27].

A systematic review underscores the diagnostic efficacy of deep learning algorithms in detecting breast and cervical cancer, emphasizing the importance of thorough examination and assessment of developing technologies [28]. Deficiencies in current research, such as a lack of forward-looking studies and dependence on limited datasets, are highlighted, raising concerns about potential biases. The review stresses the significance of defined criteria and global collaboration to enhance the reliability of deep learning algorithms for breast and cervical cancer identification in medical imaging. Building upon Vargas-Cardona's work, our discussion focuses on the profound impact of AI in cervical cancer screening, specifically highlighting the transition towards convolutional neural networks (CNN) and the collaborative possibilities arising from the integration of ML and DL algorithms [29].

Ongoing challenges, such as variations in studies and small sample sizes, underscore the importance of standardization and adherence to reporting requirements like MI-CLAIM. Consistent with the findings of another study, this systematic study emphasizes the positive trajectory of AI applications in the diagnosis and screening of cervical cancer [30]. It underscores the importance of continually enhancing and expanding machine learning approaches. Consequently, AI has the potential to significantly transform cervical cancer healthcare, enhancing diagnostic accuracy, reducing the workload of clinicians, and supporting global initiatives to eliminate cervical cancer.

### 4.1. Limitations

This systematic review offers valuable insights into the evolving landscape of machine learning (ML) and artificial intelligence (AI) in cervical cancer screening. However, it's important to note several limitations. By focusing solely on studies published after 2019 and highlighting recent accomplishments, there's a risk of overlooking essential foundational research. Moreover, giving preference to English-language publications could introduce a linguistic bias, potentially overlooking relevant studies in other languages. The diverse range of study approaches, which involve integrating various AI models and datasets, presents challenges in synthesizing findings. Recognizing these limitations is essential for thoroughly evaluating the findings within the study's defined parameters.

### 4.2. Clinical Implications

The review underscores the significant therapeutic implications of incorporating AI and ML technologies, exemplified by CytoBrain and CervDetect, in cervical cancer screening. These advancements showcase the potential to enhance diagnostic precision, streamline screening procedures, and reduce the necessity for unnecessary treatments. The increasing prevalence of AI applications, particularly in predicting outcomes, underscores the potential for early detection of issues. The shift towards CNN (Convolutional Neural Network) and collaborative Machine Learning/Deep Learning techniques opens avenues for further advancements. To ensure the proper integration of AI in healthcare, it is imperative to address critical issues such as ethics and interpretability.

## 5. CONCLUSION

In conclusion, the systematic review highlights the significant impact of machine learning (ML) and artificial intelligence (AI) on cervical cancer screening. Technologies like CytoBrain, ResNet101, FSOD-GAN, and Decision Tree models demonstrate high diagnostic accuracy, promising advancements in early detection and precise classification of cervical abnormalities. Integration of AI and ML technologies, exemplified by CytoBrain and CervDetect, shows potential for improving diagnostic precision and reducing unnecessary treatments. Additionally, AI incorporation in digital microscopy and predictive modeling enhances sensitivity and decreases unnecessary procedures. The review emphasizes the growing use of AI, particularly convolutional neural networks (CNN) and collaborative ML/DL approaches, in predicting outcomes, highlighting the importance of addressing challenges in cervical cancer screening and diagnosis.

### Compliance with Ethical Standards


- **Funding:** The authors did not receive support from any organization for the submitted work.
- **Conflicts of Interest:** The authors declare no conflict of interest. The authors have no relevant financial or non-financial interests to disclose.
- **Ethical Approval:** This article does not contain any studies with human participants performed by any of the authors.
- **Informed Consent:** Not applicable
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