

Development and Validation of a Culturally Tailored mHealth-Based Risk Assessment Model for Early Cervical Cancer Detection in Bangladeshi Women



Kamruzzaman Mithu ^{1*}, Zakaria ¹, Sheikh Fahad ², Arindam Khaled ³, Khondaker Abdullah Al Mamun ¹

Abstract

Background: Cervical cancer continues to impose a disproportionate health burden on women living in low- and lower-middle-income countries, where access to organized screening programs often remains limited. In Bangladesh, participation in conventional cervical cancer screening is frequently hindered by cultural discomfort, limited healthcare accessibility, and hesitancy toward invasive gynecological procedures. These challenges highlight the need for alternative, community-oriented approaches capable of supporting early risk identification in resource-constrained settings. This study aimed to develop and validate a culturally tailored, questionnaire-based mHealth model for early cervical cancer risk assessment among Bangladeshi women. **Methods:** A community-based cross-sectional validation study was conducted among 400 women recruited from two geographically distinct regions of Bangladesh in collaboration with Friendship NGO. The proposed model integrated personal risk factors, family history variables, and symptom-based assessment within a structured scoring framework embedded into a mobile health application named CerviCheck. Physician-led clinical evaluation was used as the comparative reference standard. Model performance was assessed using sensitivity, specificity, accuracy, positive predictive value,

negative predictive value, logistic regression analysis, and receiver operating characteristic (ROC) curve analysis. **Results:** The study cohort demonstrated substantial prevalence of known cervical cancer-associated behavioral and reproductive risk factors, including early sexual debut, high parity, and tobacco exposure. The proposed model achieved an overall accuracy of 88.25%, with sensitivity reaching 100% and specificity estimated at 87.5%. Logistic regression analysis further demonstrated strong predictive contribution from symptom-related variables. ROC curve analysis yielded an area under the curve (AUC) of 0.987, indicating excellent discriminatory performance. Internal cross-validation suggested consistent model stability across the study dataset. **Conclusion:** The findings suggest that culturally adapted mHealth-based questionnaire systems may offer promising supportive tools for preliminary cervical cancer risk stratification in underserved populations. While not intended to replace clinical diagnostics, the proposed framework may improve early awareness, facilitate referral prioritization, and support community-level preventive screening initiatives in low-resource settings.

Keywords

Author Affiliation: ¹Department of Computer Science & Engineering, United International University, Dhaka, Bangladesh.

²Department of Computer Science & Engineering, Independent University, Bangladesh, Dhaka, Bangladesh.

³Department of Computer Science & Engineering, Mississippi State University, Mississippi, USA.

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Significance | Culturally tailored mHealth screening may improve early cervical cancer risk identification and referral accessibility among underserved women in Bangladesh.

*Correspondence.

Kamruzzaman Mithu, Department of Computer Science & Engineering, United International University, Dhaka, Bangladesh. E-mail: kmithu213046@mscse.uiu.ac.bd, kamruzzamansmithu@gmail.com.

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1.Introduction

Cervical cancer continues to represent one of the most persistent and deeply unequal public health burdens affecting women worldwide. Although considerable progress has been achieved in prevention, vaccination, and screening technologies over the past several decades, the disease still disproportionately affects women living in low- and lower-middle-income countries (LMICs), where access to organized screening programs and early diagnostic services remains limited. Globally, cervical cancer ranks as the fourth most common cancer among women, with hundreds of thousands of new cases and deaths reported annually (Arbyn et al., 2020). Yet the burden of this disease is not distributed evenly. Nearly 90% of cervical cancer-related deaths occur in resource-constrained countries, where healthcare systems often struggle with limited infrastructure, inadequate screening coverage, delayed diagnosis, and insufficient public awareness regarding reproductive health and preventive care (Arbyn et al., 2020). In many of these settings, cervical cancer is not simply a medical issue; rather, it intersects with broader social, cultural, economic, and gender-related inequalities that continue to shape women's access to healthcare services.

Bangladesh presents a particularly concerning example of this disparity. Cervical cancer remains one of the leading cancers among Bangladeshi women and continues to contribute substantially to female morbidity and mortality. According to reports from the International Agency for Research on Cancer (IARC), cervical cancer is currently the second most prevalent cancer among women in Bangladesh, accounting for a considerable proportion of all female cancer cases. More than 50 million women in the country are believed to be at risk of developing the disease, while thousands of new cases and deaths are reported every year. The overwhelming majority of these cases are associated with persistent infection by high-risk strains of human papillomavirus (HPV), which has long been recognized as the primary etiological factor underlying cervical carcinogenesis (Arbyn et al., 2020). Despite growing awareness globally regarding HPV vaccination and early screening strategies, implementation within many low-resource regions remains inconsistent and fragmented. Consequently, a large number of women continue to receive diagnoses only after the disease has

progressed to advanced stages, significantly reducing treatment success and survival outcomes.

Early detection has consistently been regarded as one of the most effective strategies for reducing cervical cancer mortality. Screening approaches such as Pap smear testing, HPV DNA testing, and visual inspection with acetic acid (VIA) have demonstrated substantial success in identifying precancerous lesions before progression into invasive malignancy. In high-income countries, organized national screening programs have dramatically reduced both incidence and mortality rates over time. However, translating these successes into LMIC contexts has proven considerably more challenging. In Bangladesh, several structural and sociocultural barriers continue to impede the widespread adoption of cervical cancer screening services. Healthcare facilities capable of conducting routine screening are frequently concentrated in urban centers, making accessibility difficult for women residing in rural or geographically isolated communities. Financial constraints, transportation difficulties, social stigma, and limited health literacy further complicate participation in preventive care programs.

Beyond infrastructural barriers, there are also deeply rooted cultural and psychological factors that influence women's willingness to undergo conventional cervical cancer screening procedures. Many women report discomfort, embarrassment, fear, or hesitation toward invasive or semi-invasive examinations such as Pap smears and HPV testing. In conservative social settings, discussions surrounding reproductive health and sexual behavior often remain highly sensitive, which may discourage women from seeking medical attention even when symptoms arise. This reluctance frequently contributes to delayed diagnosis and increases the likelihood that cervical abnormalities remain undetected until more advanced disease stages emerge. Such realities underscore the urgent need for alternative, culturally acceptable, and non-invasive approaches capable of supporting earlier risk identification among vulnerable populations.

In recent years, questionnaire-based risk assessment models have attracted increasing attention as complementary tools for cancer screening and preventive healthcare. Rather than replacing clinical diagnostics, these models attempt to identify individuals who may possess elevated risk profiles based on demographic characteristics, behavioral factors, reproductive history,

symptom patterns, and family medical history. In several developed healthcare systems, algorithm-assisted risk stratification tools are now used to prioritize high-risk individuals for follow-up examinations and preventive interventions. Such approaches offer several practical advantages, particularly in settings where healthcare resources are limited. Questionnaire-based systems are generally low-cost, scalable, non-invasive, and capable of reaching populations that might otherwise remain outside formal screening frameworks.

At the same time, however, the effectiveness of these tools depends heavily on cultural adaptation and contextual relevance. Risk factors, healthcare behaviors, social norms, and symptom-reporting patterns often vary substantially across populations. Models developed within high-income countries may therefore fail to adequately capture the lived realities and healthcare dynamics present in LMIC communities such as Bangladesh. Cultural tailoring becomes especially important when addressing sensitive topics related to sexual behavior, reproductive history, and gynecological symptoms. Without careful adaptation, even well-designed screening initiatives may struggle to achieve meaningful community acceptance and engagement.

The growing expansion of mobile health (mHealth) technologies presents another promising opportunity in this context. Over the last decade, mobile phone usage has increased dramatically across South Asia, including among populations with limited access to traditional healthcare infrastructure. mHealth platforms have already demonstrated potential in areas such as maternal health monitoring, chronic disease management, vaccination campaigns, and public health education. Their portability, accessibility, and relatively low implementation cost make them particularly attractive for preventive healthcare initiatives in resource-constrained settings. Importantly, mHealth systems may also provide a degree of privacy and autonomy that encourages participation among women who might otherwise avoid face-to-face clinical consultations for culturally sensitive conditions.

Against this backdrop, the present study proposes the development of a culturally tailored, questionnaire-based risk assessment model integrated into an mHealth application for the early detection of cervical cancer risk among Bangladeshi women. Rather than functioning as a definitive diagnostic tool, the proposed framework is intended to serve as an early-stage triage and awareness-

support system capable of identifying individuals who may benefit from further clinical evaluation. The model incorporates multiple domains associated with cervical cancer risk, including personal risk factors, family history, reproductive and behavioral characteristics, and symptom assessment. By combining these variables within a structured algorithmic framework, the system aims to generate individualized risk stratification categories that may facilitate timely referral and intervention.

A particularly important feature of this approach lies in its emphasis on contextual sensitivity. The questionnaire and educational components were designed with consideration for linguistic accessibility, cultural appropriateness, and local healthcare realities within Bangladesh. Both Bengali and English content were incorporated to improve usability across diverse population groups, including rural women who may possess limited formal education or healthcare literacy. In this sense, the study moves beyond purely technical model development and attempts to address broader issues related to accessibility, inclusivity, and community engagement in preventive women's healthcare.

Nevertheless, it is important to recognize that questionnaire-based assessment models also possess inherent limitations. Self-reported data may be influenced by recall bias, social desirability bias, or incomplete symptom recognition. Moreover, risk estimation models cannot substitute for definitive diagnostic procedures such as cytology, HPV testing, colposcopy, or histopathological evaluation. Rather, their value lies in improving preliminary risk awareness, expanding outreach capacity, and encouraging earlier healthcare engagement among populations that might otherwise remain underserved. Within low-resource environments where screening infrastructure is limited, even modest improvements in early identification and referral pathways may contribute meaningfully to reducing disease burden.

Therefore, the objective of this study is to develop and validate a culturally adapted mHealth-based questionnaire model capable of supporting early cervical cancer risk assessment among women in Bangladesh. By integrating demographic, behavioral, familial, and symptom-related variables within an accessible digital platform, this research seeks to explore whether non-invasive, community-oriented screening support tools can enhance early risk recognition in resource-constrained settings. Ultimately, the study aims to contribute not only to the

growing field of digital health and preventive oncology, but also to broader efforts focused on improving equitable access to women's healthcare in underserved populations.

2. Methodology

2.1 Study Design and Conceptual Framework

This study was designed as a community-based, cross-sectional validation study aimed at developing and evaluating a culturally tailored questionnaire-driven risk assessment model for the early detection of cervical cancer among women in Bangladesh. The overall methodological framework was intentionally structured to address several persistent challenges commonly encountered in low-resource settings, including limited access to gynecological screening services, cultural hesitancy toward invasive examinations, and inadequate awareness regarding cervical cancer prevention. Rather than functioning as a definitive diagnostic tool, the proposed model was conceptualized as an early-stage digital triage and risk stratification system intended to identify women who may require further clinical evaluation.

The study combined epidemiological risk profiling, symptom-based assessment, and family history analysis within a rule-based scoring architecture integrated into an mHealth application named *CerviCheck*. The methodological approach was informed by previously established cervical cancer risk determinants reported in epidemiological, clinical, and public health literature (Arbyn et al., 2020; Ghebre et al., 2017). Particular emphasis was placed on contextual adaptation to ensure that the questionnaire remained understandable, culturally acceptable, and practically deployable among both urban and rural populations in Bangladesh.

2.2 Study Setting and Participant Recruitment

The validation phase of the study was conducted in collaboration with Friendship NGO, a humanitarian healthcare organization operating in underserved regions of Bangladesh. Data collection was carried out in two geographically and socioeconomically distinct regions: Kurigram, located in the northern part of the country, and Shyamnagar, situated in the southern coastal belt. These locations were selected intentionally to capture demographic diversity, variations in healthcare accessibility, and differing sociocultural environments that may influence women's reproductive health behaviors.

A total of 400 adult women participated in the study, with

200 participants recruited from each study site. Recruitment was performed through community outreach activities facilitated by local healthcare workers and NGO coordinators. Women attending community health camps, reproductive health awareness programs, or routine healthcare consultations were informed about the study and invited to participate voluntarily.

Participants were eligible for inclusion if they:

- Were female,
- Were aged 18 years or older,
- Were capable of providing informed consent,
- Possessed sufficient cognitive ability to complete the questionnaire interview process.

Participants were excluded if they:

- Were critically ill during data collection,
- Declined participation,
- Had incomplete questionnaire responses exceeding 20% missing data.

Because literacy levels varied substantially across the study population, trained female interviewers administered the questionnaire verbally when necessary. This approach was adopted to minimize exclusion bias associated with educational disparities and to improve participant comfort during sensitive discussions involving reproductive health.

2.3 Ethical Considerations

Ethical approval for the study was obtained from the appropriate institutional ethical review authority prior to participant enrollment. All procedures involving human participants were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants before data collection commenced.

To preserve confidentiality and participant privacy, each individual was assigned a unique anonymized study identification code. No personally identifiable information was included within the analytical dataset. Participants were informed that the questionnaire-based assessment was not a substitute for medical diagnosis and that women categorized as moderate or high risk would be advised to seek formal clinical evaluation at nearby healthcare facilities.

Given the culturally sensitive nature of reproductive and sexual health discussions in Bangladesh, interviews were conducted in private settings whenever possible. Female healthcare personnel and trained female interviewers were prioritized during participant interaction to minimize discomfort and improve response reliability.

2.4 Development of the Questionnaire Framework

The questionnaire framework was developed through a multistage process involving literature review, contextual adaptation, clinical consultation, and pilot refinement. Initially, a comprehensive review of published cervical cancer epidemiology studies, WHO guidance documents, and cervical cancer risk prediction literature was conducted to identify variables consistently associated with elevated disease risk (Arbyn et al., 2020; American Cancer Society, 2023).

Risk factors were subsequently grouped into three major domains:

- Personal Risk Factors (PRF)
- Family Risk Factors (FRF)
- Cervical Cancer Symptom Assessment (CCSA)

The decision to separate these domains was based on the understanding that cervical cancer risk does not emerge from a single determinant but rather from the interaction of behavioral, biological, hereditary, and symptomatic factors.

The preliminary questionnaire underwent expert review involving physicians, public health researchers, and digital health collaborators associated with the Prescriptec project. Questions were refined to improve linguistic clarity, cultural sensitivity, and participant comprehension. The final questionnaire consisted of 16 structured items delivered in both Bengali and English.

2.5 Personal Risk Factor (PRF) Assessment

The PRF component evaluated demographic, behavioral, and reproductive variables previously associated with cervical cancer risk in epidemiological studies (Rahman et al., 2022). Variables included:

- age,
- educational attainment,
- marital and sexual activity status,

- age at sexual debut,
- parity,
- number of marriages,
- abortion or miscarriage history,
- smoking or tobacco use,
- contraceptive use,
- history of abdominal or pelvic surgery,
- awareness regarding cervical cancer,
- presence of comorbid diseases (Table 1).

Each variable was transformed into categorical numerical values based on predefined thresholds derived from prior literature and contextual clinical reasoning (Table 2). For example, age categories were stratified into:

- <30 years,
- 30–39 years,
- 40–49 years,
- 50 years,

reflecting established epidemiological trends demonstrating increased cervical cancer incidence with advancing age (Arbyn et al., 2020).

Similarly, early sexual debut (<15 years), multiple pregnancies, smoking exposure, and low educational attainment were weighted positively within the cumulative risk score because these variables have repeatedly been associated with increased cervical cancer susceptibility in previous studies (Ghebre et al., 2017). The complete scoring thresholds applied to each variable are presented in Table 3.

The cumulative PRF score was calculated using the following equation:

$CPRF = \sum_{i=1}^n PRFi$

where:

- *CPRF* represents the cumulative personal risk factor score,
- *PRFi* represents the individual weighted risk variables,
- *n* denotes the total number of PRF variables included in the model.

Participants were then categorized into:

- low risk,
- moderate risk,
- high risk

based on predefined score thresholds (Table 4).

2.6 Family Risk Factor (FRF) Assessment

The FRF domain was designed to estimate hereditary predisposition associated with cervical cancer occurrence among first- and second-degree relatives. Although cervical cancer is primarily driven by HPV infection, prior studies have suggested that familial clustering and genetic susceptibility may influence disease risk under certain conditions (Ghebre et al., 2017).

Weighted scores were assigned according to familial proximity:

- first-degree relatives (mother, sister, daughter) received higher weights,
- second-degree relatives (grandmother, aunt) received lower weights (Table 5).

The FRF score was calculated as:

$FRFn=Wn \times Fn$

where:

- Wn represents the assigned familial weight,
- Fn indicates whether the family member had cervical cancer (1 = yes, 0 = no).

The cumulative family risk score was subsequently derived as:

$CFRF=i=1yFRFi$

Participants were stratified into low-, moderate-, or high-risk familial categories according to cumulative score thresholds defined during model development (Table 6).

2.7 Cervical Cancer Symptom Assessment (CCSA)

The symptom assessment domain focused on common early warning manifestations associated with cervical cancer, including:

- abnormal vaginal bleeding,
- post-coital bleeding,

- inter-menstrual bleeding,
- persistent malodorous vaginal discharge,
- pelvic pain,
- pain during intercourse,
- post-menopausal bleeding.

Participants reporting one or more major symptoms were automatically categorized into elevated symptom-risk groups because such symptoms may indicate existing cervical pathology requiring urgent clinical evaluation.

Vaccination history against HPV was also included within this domain. Participants reporting prior HPV vaccination received lower symptom-related risk weighting due to the known protective effects of vaccination against high-risk HPV-associated cervical neoplasia. The complete CCSA scoring criteria are summarized in Table 7.

2.8 Clinical Validation Procedure

To evaluate the practical performance of the questionnaire-based model, participating physicians independently assessed each participant's cervical cancer risk status during community screening activities. Physicians assigned:

- “0” for participants considered clinically low risk,
- “1” for participants considered clinically at risk.

The questionnaire model outputs were subsequently compared against physician assessments to evaluate agreement and screening performance.

Importantly, the study prioritized sensitivity over specificity during model development. Moderate-risk cases were intentionally grouped alongside high-risk classifications during validation analyses to minimize false-negative outcomes. This conservative approach was selected because missed high-risk cases in cervical cancer screening may have severe clinical consequences. The final integrated risk stratification and recommendation framework is presented in Table 8, and the corresponding algorithmic decision pathway is illustrated in Figure 1.

2.9 Statistical Analysis

All collected data were entered into a structured database and analyzed using statistical software. Descriptive statistics were calculated for participant demographics and risk variables. Continuous variables were summarized

Table 1. Personal Risk Factor (PRF) Attributes Incorporated into the Cervical Cancer Risk Assessment Model. This table presents the 13 demographic, behavioral, reproductive, and clinical variables constituting the Personal Risk Factor (PRF) domain of the CerviCheck risk assessment framework. Each attribute is listed alongside its corresponding model variable code and data type (integer or Boolean), reflecting the structured scoring architecture used for individual risk quantification. Variables were selected based on established epidemiological evidence linking each factor to cervical cancer susceptibility.

Attributes	Variables	Type
Age	AGE	Integer
Educational attainment	EDU	Integer
Sexual activity based on marital status	MRSTA	Integer
Age at sexual debut	SXDBT	Integer
Total number of sexual partners	SXPTR	Integer
Parity	PARITY	Integer
Total number of marriages	TLMAR	Integer
Total number of abortions or miscarriages	TLABR	Integer
History of previous abdominal or pelvic surgery	isPLV	Boolean
Have you ever used contraceptives	CNTRCEP	Integer
History of smoking/tobacco use	SMOKE	Integer
What other diseases do you have	DISEASE	Integer
Have you ever heard of cervical cancer	knwCS	Boolean

Table 2. Possible PRF Score Values Assigned to Each Personal Risk Factor Variable. This table enumerates the complete range of permissible numerical values assignable to each PRF variable within the scoring model. Dichotomous variables (e.g., isPLV, knwCS) are assigned binary values (0 or 1), while continuous or count-based variables (e.g., PARITY, TLMAR, TLABR, SXPTR) may accumulate incrementally, allowing individualized risk quantification based on cumulative exposure.

Variables	Possible PRF Values
AGE	0, 1, 2, 3
EDU	0, 1
MRSTA	0, 1
SXDBT	0, 1
SXPTR	0, 1
PARITY	0, 1, 2, 3, 4, 5...
TLMAR	0, 1, 2, 3...
TLABR	0, 1, 2, 3...
isPLV	0, 1
CNTRCEP	0, 1
SMOKE	0, 1

DISEASE	0, 1, 2, 3, 4
knwCS	0, 1

Table 3. Predefined PRF Scoring Thresholds and Risk Weights for Each Variable. This table details the risk-scoring criteria applied to each PRF variable, derived from published epidemiological evidence and clinical guidelines. Age stratification, educational level, marital and sexual activity status, age at sexual debut, parity, number of marriages, abortion history, pelvic surgical history, contraceptive use, tobacco exposure, comorbid disease burden, and cervical cancer awareness are each assigned threshold-based numerical scores. Incremental scoring is applied for count-based variables to reflect cumulative biological and behavioral risk accumulation. Note. PRF = Personal Risk Factor; HPV = Human Papillomavirus; HIV = Human Immunodeficiency Virus. Higher scores indicate greater cumulative personal risk.

Variables	PRF Score
AGE	
< 30 years	0
30–39 years	1
40–49 years	2
50 years	3
EDU	
Higher level of sexual health awareness	0
Lower level of sexual health awareness	1
MRSTA	
Sexually inactive	0
Sexually active	1
SXDBT	
15 years	0
< 15 years	1
SXPTR	+1 for each sexual partner
PARITY	+1 for each childbirth
TLMAR	+1 for each marriage
TLABR	+1 for each abortion/miscarriage
isPLV	
No	0
Yes	1
CNTRCEP	
Never used	0

Currently using	1
Previously used	1
SMOKE	
Never used	0
Currently using	1
Previously used	1
DISEASE	
None	0
Diabetes mellitus	1
Hypertension	2
Oncological disease	3
HIV/AIDS	4
knwCS	
No awareness of cervical cancer	0
Aware of cervical cancer	1

Table 4. Risk Category Classification Based on Cumulative PRF Score. This table defines the three-tiered risk stratification scheme applied to cumulative PRF scores within the CerviCheck model. Women scoring 0–3 are classified as Low Risk, those scoring 4–7 as Moderate Risk, and those scoring 8 or above as High Risk. These thresholds were established during model development to align with recognized cervical cancer risk epidemiology and to optimize referral sensitivity within resource-constrained screening contexts.

Score	PRF Category
0–3	Low Risk
4–7	Moderate Risk
8	High Risk

using means and standard deviations, whereas categorical variables were presented as frequencies and percentages.

Model performance was evaluated using:

- accuracy,
- sensitivity,
- specificity,
- positive predictive value (PPV),
- negative predictive value (NPV),
- receiver operating characteristic (ROC) curve analysis,
- area under the ROC curve (AUC).

Multivariate logistic regression analysis was additionally performed to examine the independent contribution of PRF, FRF, and symptom-related variables toward overall cervical cancer risk classification.

Cross-validation procedures were conducted to estimate internal model consistency and predictive stability across the study cohort.

2.10 Development of the CerviCheck mHealth Application

The finalized questionnaire model was integrated into an Android-compatible mHealth application named *CerviCheck*. The application was designed to provide:

- multilingual accessibility,
- simplified navigation,
- secure data storage,
- repeatable self-assessment capability.

Educational content regarding cervical cancer awareness, prevention, and screening was embedded within the platform in both Bengali and English to improve health literacy and community engagement.

User data were encrypted during storage and transmission. Access to identifiable research data was restricted exclusively to authorized investigators through role-based authentication procedures. The application architecture was intentionally designed to remain lightweight and deployable within low-bandwidth environments commonly encountered in rural Bangladesh.

Overall, the methodological design sought to balance scientific rigor, reproducibility, contextual relevance, and practical scalability, acknowledging both the opportunities and limitations inherent in questionnaire-based digital health screening systems for cervical cancer prevention.

3. Results

4.1 Demographic and Clinical Characteristics of the Study Cohort

A total of 400 women from two geographically distinct regions of Bangladesh participated in the present validation study. The cohort represented a diverse community-based population encompassing women from both northern and southern rural settings, thereby allowing the assessment model to be evaluated within varying sociocultural and healthcare-access environments. The mean age of the participants was 35.9 years, suggesting that the majority of respondents belonged to an age group generally considered relevant for early cervical cancer risk surveillance and reproductive health monitoring (Table 9).

Age distribution analysis demonstrated that most participants were between 30 and 39 years of age (55.0%), followed by women aged 40–49 years (30.0%). Comparatively fewer participants were younger than 30 years (12.5%), while only a small proportion were aged 50 years or older (2.5%) (Table 9). This age pattern is noteworthy because cervical cancer risk has repeatedly been shown to increase with age, particularly among women with prolonged exposure to persistent high-risk HPV infection and cumulative reproductive risk factors (Arbyn et al., 2020).

With respect to marital and sexual activity status, the overwhelming majority of participants were categorized as sexually active (86.25%), whereas only 13.75% reported being sexually inactive (Table 9). Since HPV transmission remains closely associated with sexual exposure, this finding reflects a population potentially vulnerable to cervical cancer-associated risk accumulation over time.

A particularly striking observation emerged in relation to age at sexual debut. Approximately two-thirds of participants (67.5%) reported initiating sexual activity before the age of 15 years, while only 32.5% reported sexual debut at or beyond 15 years of age (Table 9). Early sexual debut has long been recognized as an important epidemiological risk factor because the immature cervical epithelium may be more susceptible to persistent HPV

Table 5. Family Risk Factor (FRF) Weighting Scheme by Familial Relationship. This table presents the differential familial weights assigned to first- and second-degree relatives within the FRF domain of the CerviCheck model. First-degree relatives (mother, sister, daughter) are assigned a weight of 2, reflecting closer genetic proximity, while second-degree relatives (maternal and paternal grandmothers and aunts) receive a weight of 1. These weights are multiplied by the presence or absence of a cervical cancer history in each relative to derive the cumulative family risk score (CFRF). Note. FRF = Family Risk Factor; CFRF = Cumulative Family Risk Factor Score. First-degree weighting reflects established patterns of hereditary and shared environmental risk.

Family Members	Weights
Mother	2
Sister	2
Daughter	2
Grandmother (Maternal)	1
Aunt (Maternal)	1
Grandmother (Paternal)	1
Aunt (Paternal)	1

Table 6. Risk Category Classification Based on Cumulative FRF Score. This table defines the three-category classification applied to cumulative FRF scores. A score of 0 indicates Low familial risk (L); scores of 1–2 indicate Moderate risk (M); and scores exceeding 2 indicate High familial risk (H). These thresholds were derived from the weighted family history scoring architecture and are intended to capture meaningful gradations in hereditary predisposition to cervical cancer.

Score	FRF Category
0	Low Risk (L)
1–2	Moderate Risk (M)
> 2	High Risk (H)

Table 7. Cervical Cancer Symptom Assessment (CCSA) Scoring Criteria and Item Descriptions. This table presents the symptom-based assessment domain of the CerviCheck model, including specific gynecological symptoms evaluated for their clinical relevance to cervical cancer. Reported symptoms—including inter-menstrual bleeding, post-coital bleeding, post-menopausal bleeding, persistent malodorous vaginal discharge, and dyspareunia—are each assigned a score of 1, while asymptomatic status is scored as 0. HPV vaccination history is additionally incorporated, with unvaccinated status assigned a score of 1 and confirmed vaccination status assigned 0, reflecting the known prophylactic benefit of HPV immunization against high-risk cervical neoplasia. Note. CCSA = Cervical Cancer Symptom Assessment; HPV = Human Papillomavirus. Any participant reporting one or more symptomatic items is automatically escalated to the High-Risk overall category, irrespective of PRF or FRF scores.

Attributes	Variable	CCSA Score
Which of the following symptoms do you currently have?	SYMPTOMS	
Inter-menstrual bleeding		1
Persistent smelly vaginal discharge		1

Discomfort or pain during sexual intercourse		1
Post-coital bleeding		1
Post-menopausal bleeding		1
Lack of symptoms from genital areas		0
Have you ever been vaccinated against HPV?	VACCINE	
Yes		0
No		1

Table 8. Final Integrated Risk Assessment Framework Combining PRF, FRF, and CCSA Domains. This table presents the composite risk stratification algorithm governing overall cervical cancer risk classification within the CerviCheck model. Overall risk category—Low, Moderate, or High—is derived from the combinatorial interaction of CCSA, PRF, and FRF scores. Participants reporting any cervical cancer symptom (CCSA = 1) are automatically classified as High Risk and recommended for intensive clinical screening. Among asymptomatic participants, overall risk is determined by PRF and FRF category combinations, with High or Moderate–High PRF–FRF profiles triggering escalated screening recommendations. All risk categories are paired with structured clinical recommendations to guide appropriate referral and follow-up action. Note. PRF = Personal Risk Factor; FRF = Family Risk Factor; CCSA = Cervical Cancer Symptom Assessment; L = Low; M = Moderate; H = High. Intensive screening referral is indicated for all High-Risk classifications regardless of symptom status.

CCRA Category	PRF Category	FRF Category	Overall Risk Category	Recommendation
0	0–4	L	Low	Regular screening
0	5–9	H/M	Moderate	Regular screening
0	10	H/M	High	Intensive screening
1+	–	–	High	Intensive screening
0	–	–	Low	Regular screening

Table 9. Baseline Sociodemographic and Reproductive Characteristics of the Study Cohort (N = 400). This table summarizes the distribution of key sociodemographic, behavioral, and reproductive characteristics among the 400 women enrolled in the community-based cross-sectional validation study. Participants were recruited from two geographically and socioeconomically distinct regions of Bangladesh (Kurigram and Shyamnagar) in collaboration with Friendship NGO. Characteristics include age distribution, sexual activity based on marital status, age at sexual debut, parity, total number of marriages, history of abdominal or pelvic surgery, contraceptive use pattern, and tobacco or smoking exposure. Frequencies and proportions are reported for all categorical variables. The mean participant age was 35.9 years. Note. N = total study sample; % = percentage of total participants. MRSTA = Marital Status-Based Sexual Activity; SXDBT = Age at Sexual Debut; PARITY = number of full-term deliveries; TLMAR = Total Number of Marriages; isPLV = History of Abdominal or Pelvic Surgery; CNTRCEP = Contraceptive Use Status; SMOKE = Smoking or Tobacco Use History.

Variables	No. (%)
Total Participants	400
Mean Age (years)	35.9
AGE	
< 30 years	50 (12.5%)
30–39 years	220 (55.0%)
40–49 years	120 (30.0%)
50 years	10 (2.5%)
MRSTA (Sexual Activity Based on Marital Status)	
Sexually inactive	55 (13.75%)
Sexually active	345 (86.25%)
SXDBT (Age at Sexual Debut)	
15 years	130 (32.5%)
< 15 years	270 (67.5%)
PARITY	
0	80 (20.0%)
1–3	153 (38.25%)
> 4	167 (41.75%)
TLMAR (Total Number of Marriages)	
0	20 (5.0%)
1	153 (38.25%)
> 1	227 (56.75%)
isPLV (History of Abdominal/Pelvic Surgery)	

No	395 (98.75%)
Yes	5 (1.25%)
CNTRCEP (Contraceptive Use)	
Never used	68 (17.0%)
Currently using	232 (58.0%)
Previously used	100 (25.0%)
SMOKE (Smoking/Tobacco Use)	
Never used	180 (45.0%)
Currently using	133 (33.25%)
Previously used	87 (21.75%)

infection and subsequent neoplastic transformation (Arbyn et al., 2020). The relatively high proportion observed in this cohort perhaps reflects broader sociocultural and early-marriage dynamics frequently encountered within resource-limited settings.

Reproductive history analysis further demonstrated a substantial prevalence of high parity among participants. While 20.0% of women reported no childbirth history, 38.25% had experienced one to three childbirths, and 41.75% reported more than four childbirths (Table 9). This trend is particularly relevant because multiple full-term pregnancies have previously been associated with increased cervical cancer susceptibility, potentially due to hormonal influences, prolonged cervical transformation zone exposure, and cumulative reproductive stressors.

Marriage history within the cohort also revealed notable patterns. Only 5.0% of participants had never been married, whereas 38.25% reported one marriage and 56.75% reported multiple marriages (Table 9). Although marital status alone is not directly causative, repeated marital transitions may indirectly reflect cumulative sexual exposure and increased opportunities for HPV transmission.

Regarding prior abdominal or pelvic surgical history, almost all participants (98.75%) reported no history of pelvic or abdominal surgery, while only 1.25% reported previous procedures (Table 9). Although this variable did not appear highly prevalent within the present cohort, it was retained in the model because previous pelvic interventions may occasionally influence gynecological health status or symptom interpretation.

Patterns related to contraceptive use demonstrated substantial variability. Current contraceptive use was reported by 58.0% of participants, while 25.0% indicated previous use and 17.0% reported never using contraceptives (Table 9). Long-term hormonal contraceptive exposure has previously been discussed within cervical cancer epidemiological literature, although findings remain somewhat heterogeneous across different populations and healthcare contexts (Ghebre et al., 2017).

Smoking and tobacco exposure, another recognized cervical cancer-associated behavioral risk factor, was also relatively common in the study population. Nearly half of participants (45.0%) reported never using tobacco products, whereas 33.25% were current users and 21.75% identified as former users (Table 9). Tobacco-

related carcinogenic exposure may contribute to cervical epithelial damage and impaired local immune responses, thereby potentially facilitating HPV persistence and disease progression.

Overall, the cohort characteristics revealed a population exhibiting multiple overlapping behavioral, reproductive, and demographic risk factors traditionally associated with cervical cancer susceptibility. Importantly, these findings underscore the practical need for accessible community-level risk assessment systems capable of identifying vulnerable individuals before progression toward advanced disease states.

4.2 Performance of the Questionnaire-Based Risk Assessment Model

The primary objective of this study was to evaluate whether a culturally tailored questionnaire-driven mHealth model could reasonably identify women at elevated cervical cancer risk within a resource-constrained population. To assess this, the performance of the model was compared against physician-led clinical risk evaluation conducted during the validation phase.

Among the 400 participants included in the analysis, 22 women were clinically categorized as having elevated cervical cancer risk based on physician assessment. In contrast, the questionnaire-driven model identified 69 participants as belonging to moderate- or high-risk categories. Although the model generated a larger number of positive classifications relative to physician evaluation, this discrepancy was intentional to some extent because the framework was designed with strong emphasis on sensitivity rather than specificity.

From a public health perspective, minimizing false-negative outcomes was considered particularly important. Missing potentially high-risk individuals in low-resource settings could delay referral and intervention, ultimately contributing to poorer clinical outcomes. Consequently, the model was intentionally calibrated to function conservatively, favoring broader identification of potentially vulnerable individuals over overly restrictive classification thresholds.

Performance evaluation demonstrated that the proposed model achieved an overall accuracy of 88.25%. Sensitivity reached 100%, indicating that all clinically identified at-risk cases were successfully captured by the questionnaire-based system. Specificity was estimated at approximately

87.5%, reflecting a relatively strong ability to correctly identify low-risk individuals while still maintaining conservative screening behavior.

The positive predictive value (PPV) of the model was calculated at 31.9%, whereas the negative predictive value (NPV) reached 100%. The exceptionally high NPV is particularly noteworthy because it suggests that participants categorized as low risk by the model were highly unlikely to belong to clinically elevated-risk groups. In practical community-health contexts, this characteristic may hold substantial value by helping prioritize limited clinical resources toward women requiring further evaluation.

4.3 Contribution of PRF, FRF, and Symptom Assessment Variables

To further explore the influence of individual risk domains on final model prediction, the effects of Personal Risk Factors (PRF), Family Risk Factors (FRF), and Cervical Cancer Symptom Assessment (CCSA) variables were examined separately.

The analysis suggested that PRF and symptom-related variables contributed substantially to overall risk classification, whereas FRF appeared to exert comparatively weaker influence within the present cohort. This observation may partly reflect the relatively limited number of participants reporting confirmed familial cervical cancer history. It is also possible that awareness regarding family cancer history remained incomplete among some participants, particularly within rural communities where diagnostic confirmation and medical record accessibility may historically have been limited.

Symptom-related variables appeared especially influential during risk prediction. Participants reporting abnormal bleeding patterns, persistent vaginal discharge, or post-coital symptoms were considerably more likely to fall into moderate- or high-risk categories. Clinically, this finding aligns with previous evidence indicating that symptom recognition remains a critical component of cervical cancer triage and early detection efforts (Ghebre et al., 2017).

4.4 Logistic Regression and Predictive Analysis

To better understand the predictive behavior of the model, multivariate logistic regression analysis incorporating 17 variables was subsequently performed. The regression analysis further reinforced the importance of symptom-related variables within the overall predictive structure.

The logistic regression model demonstrated an overall accuracy of 85.0%, accompanied by a sensitivity of 95.92% and specificity of 99.64%. These findings suggest that symptom-driven and behavioral variables retained strong discriminatory capacity even when analyzed collectively within a multivariable framework.

Receiver operating characteristic (ROC) curve analysis additionally demonstrated robust predictive performance. The area under the ROC curve (AUC) reached 0.987, indicating excellent discrimination between clinically elevated-risk and low-risk individuals (Figure 4). An AUC value approaching 1.0 generally reflects highly effective classification performance, suggesting that the integrated questionnaire framework possessed considerable ability to differentiate between varying levels of cervical cancer risk within the study population.

The ROC findings also support the broader conceptual rationale underlying the study—that structured symptom assessment combined with demographic and behavioral risk profiling may provide meaningful preliminary screening support in settings where conventional diagnostic infrastructure remains limited.

4.5 Internal Validation and Model Stability

Internal cross-validation procedures were conducted to examine the stability and consistency of model performance across the dataset. Cross-validation analysis yielded an overall accuracy estimate of approximately 95.98%, suggesting that the framework maintained relatively stable predictive behavior within repeated validation iterations.

Nevertheless, these findings should be interpreted cautiously. Although the internal validation results were encouraging, the current cohort size remained relatively modest, and the number of clinically elevated-risk cases was comparatively limited. Therefore, while the present results suggest promising screening utility, larger multicenter studies involving more demographically diverse populations will likely be necessary before broader generalization can confidently be established.

4.6 Performance of the CerviCheck mHealth Platform

Beyond numerical model performance, the practical deployment characteristics of the *CerviCheck* application were also evaluated during field implementation (Figure 2; Figure 3). Overall, participants demonstrated favorable engagement with the platform, particularly when

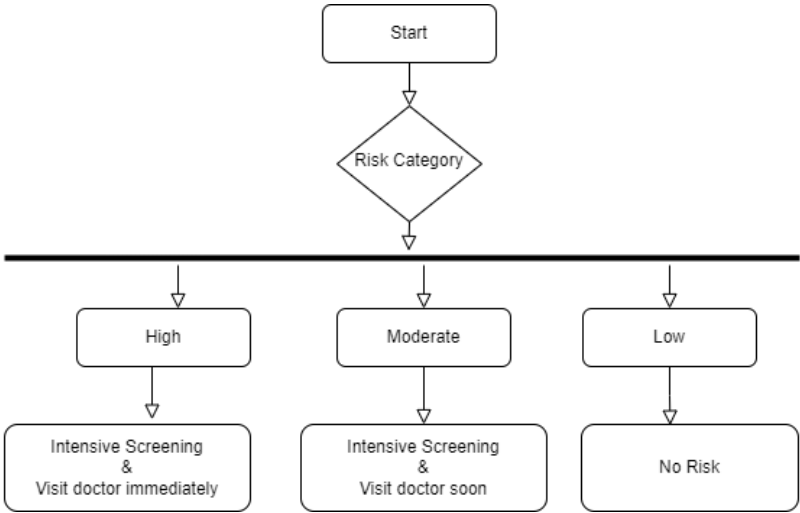


Figure 1. Algorithmic Flowchart Illustrating the Integrated Risk Stratification and Clinical Recommendation Pathway of the CerviCheck Model. This figure presents the stepwise decision logic governing the CerviCheck cervical cancer risk assessment framework. The algorithm begins with sequential evaluation of the three principal risk domains: Cervical Cancer Symptom Assessment (CCSA), Personal Risk Factor (PRF) scoring, and Family Risk Factor (FRF) scoring. Participants reporting any cervical cancer-related symptom are immediately classified as High Risk and directed toward intensive clinical screening. For asymptomatic participants, final risk categorization is determined through the combinatorial integration of PRF and FRF scores, resulting in Low, Moderate, or High overall risk classifications paired with tailored screening recommendations. The flowchart delineates all possible decision branches, threshold-based score transitions, and recommended clinical actions, thereby illustrating the operational architecture of the model as implemented within the CerviCheck mHealth application. Note. CCSA = Cervical Cancer Symptom Assessment; PRF = Personal Risk Factor; FRF = Family Risk Factor. Regular Screening = routine cervical cancer screening per national guidelines; Intensive Screening = expedited clinical referral and follow-up evaluation.

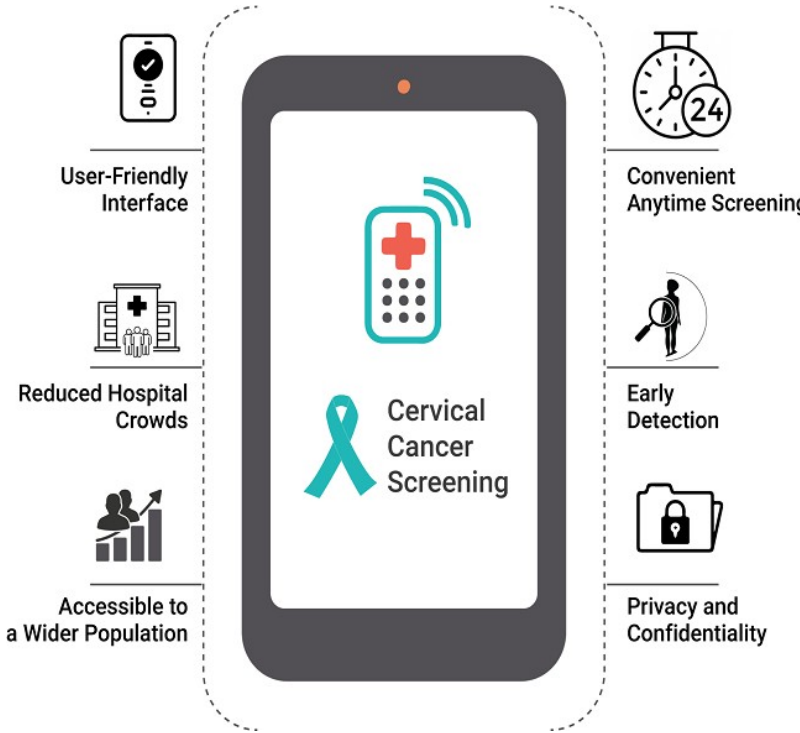


Figure 2. Overview of the CerviCheck mHealth Application Developed for Culturally Tailored Cervical Cancer Early Detection in Bangladeshi Women. This figure provides a representative overview of CerviCheck, an Android-compatible mobile health application designed to deliver the integrated cervical cancer risk assessment model in a user-accessible digital format. The application incorporates multilingual support (Bengali and English), simplified user navigation, structured questionnaire delivery, automated risk score computation, and integrated educational content pertaining to cervical cancer awareness and prevention. The application architecture was designed to maintain lightweight deployment and operational functionality within low-bandwidth environments characteristic of rural and peri-urban settings in Bangladesh. Data encryption and role-based access controls are embedded within the application to ensure participant confidentiality and data security throughout the assessment process. Note. mHealth = Mobile Health. CerviCheck was developed and deployed as an Android-compatible application to maximize accessibility across diverse socioeconomic and geographical contexts within Bangladesh.

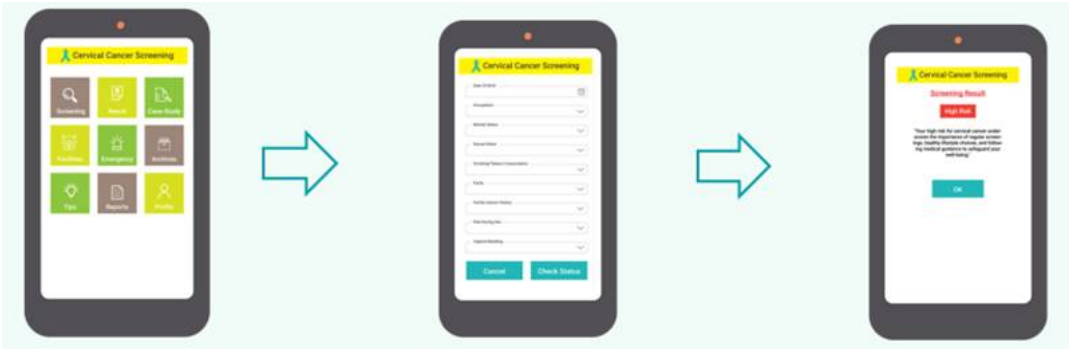


Figure 3. Representative User Interface Screens of the CerviCheck mHealth Application Demonstrating the Questionnaire Workflow, Risk Output Display, and Educational Content Modules. This figure illustrates key interface components of the CerviCheck application as encountered by end users during the risk assessment process. Displayed screens include representative questionnaire input panels corresponding to the PRF, FRF, and CCSA domains, automated risk category output screens conveying individualized Low, Moderate, or High risk classifications, and integrated health education modules promoting cervical cancer awareness and preventive practices. The interface design prioritizes visual clarity, minimal literacy requirements, and culturally appropriate iconography to facilitate usability across diverse participant groups, including women with limited formal education in rural community settings. Both Bengali and English language versions are accessible within the application. Note. PRF = Personal Risk Factor; FRF = Family Risk Factor; CCSA = Cervical Cancer Symptom Assessment. Interface screens depicted are representative examples from the validated application version used during the community-based study.

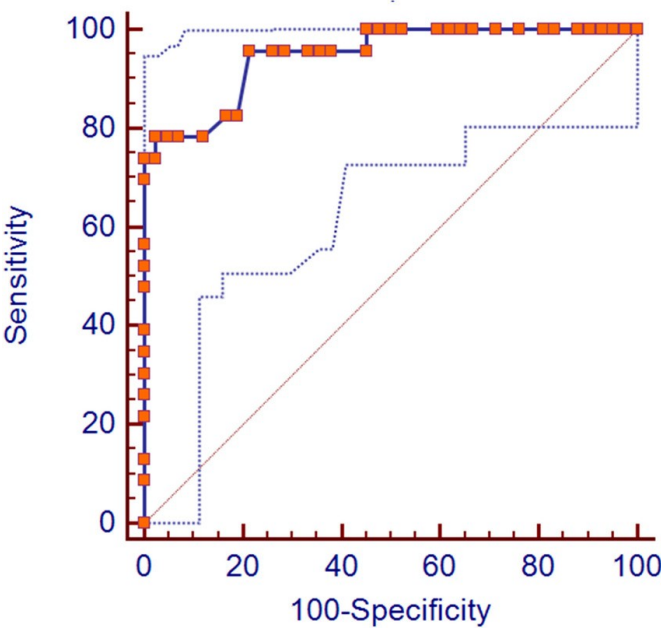


Figure 4: Receiver Operating Characteristic (ROC) Curve (AUC 0.987)

questionnaires were administered in Bengali and supported by trained female interviewers.

The bilingual interface and simplified navigation design appeared to improve accessibility among women with varying educational backgrounds. Importantly, the mobile-based structure allowed assessments to be conducted outside traditional clinical settings, potentially reducing some of the sociocultural discomfort often associated with invasive gynecological screening procedures.

Taken together, the findings suggest that culturally adapted digital risk assessment platforms may hold meaningful potential as supportive tools for community-level cervical cancer awareness, triage, and early referral initiatives in underserved populations.

5. Discussion

5.1 Interpretation of the Principal Findings

The present study sought to explore whether a culturally tailored, questionnaire-driven mHealth model could function as a practical early-stage cervical cancer risk assessment tool within resource-constrained communities in Bangladesh. Overall, the findings suggest that the proposed framework demonstrated promising discriminatory performance, particularly in its ability to identify women who may require further clinical attention. The model achieved high sensitivity alongside relatively strong specificity, indicating that the integrated combination of symptom assessment, personal risk profiling, and family history evaluation was capable of distinguishing elevated-risk individuals with encouraging consistency (Figure 4).

Perhaps one of the most important observations emerging from this study was the exceptionally high negative predictive value. In practical terms, women categorized as low risk by the model were highly unlikely to belong to clinically elevated-risk groups. Within low-resource healthcare systems, where specialist diagnostic capacity often remains limited, this characteristic may carry substantial public health significance. A screening-support tool that can reasonably identify lower-risk individuals while prioritizing potentially vulnerable women for follow-up evaluation could help optimize already strained healthcare resources.

At the same time, however, it is important to interpret these findings cautiously. The intentionally conservative structure of the model favored sensitivity over specificity,

meaning that the system was deliberately designed to minimize false-negative classifications, even if this resulted in a comparatively larger number of false-positive cases. From a clinical prevention perspective, this trade-off may actually be justified. Missing women with potentially significant cervical abnormalities in underserved settings could lead to delayed diagnosis and poorer outcomes, whereas additional follow-up screening among false-positive individuals, although resource-consuming, is generally less harmful than undetected disease progression.

5.2 Sociodemographic and Behavioral Risk Patterns Within the Cohort

The cohort characteristics revealed several overlapping demographic and behavioral factors traditionally associated with cervical cancer susceptibility (Table 9). Most participants were within the 30–49-year age range, a demographic window frequently linked with increasing cervical cancer incidence in epidemiological literature (Arbyn et al., 2020). This pattern is perhaps not surprising, considering that persistent HPV infection often requires several years before progressing toward clinically detectable cervical abnormalities.

One particularly striking finding was the high prevalence of early sexual debut among participants. More than two-thirds of the cohort reported sexual initiation before the age of 15 years (Table 9). Early sexual activity has repeatedly been identified as a major risk factor for cervical carcinogenesis because the cervical transformation zone during adolescence may remain particularly vulnerable to persistent HPV infection and epithelial dysregulation (Arbyn et al., 2020). Within the context of Bangladesh, this observation may also reflect broader sociocultural realities, including early marriage practices and limited reproductive health education in certain communities.

Similarly, high parity was widely observed within the study population, with a substantial proportion of women reporting more than four childbirths (Table 9). Previous studies have suggested that repeated pregnancies may influence cervical cancer risk through hormonal alterations, prolonged transformation zone exposure, cervical trauma, and immune modulation (Ghebre et al., 2017). While parity alone cannot be considered causative, its interaction with persistent HPV infection and limited screening access may contribute cumulatively to disease

vulnerability.

Smoking and tobacco exposure also emerged as notable behavioral features within the cohort. Although smoking prevalence among women in Bangladesh is often underreported socially, the present findings demonstrated that a considerable proportion of participants were either current or former tobacco users (Table 9). Tobacco-related carcinogens are believed to impair local cervical immune defense mechanisms and may facilitate persistent oncogenic HPV activity, thereby contributing to malignant transformation processes (Arbyn et al., 2020).

Collectively, these demographic and behavioral findings reinforce the broader notion that cervical cancer risk in low-resource settings is rarely shaped by a single determinant. Instead, it often emerges from a complex interaction among reproductive behavior, healthcare accessibility, sociocultural norms, educational status, and delayed preventive intervention.

5.3 Importance of Symptom-Based Assessment in Risk Prediction

One of the more compelling findings of the present study was the strong contribution of symptom-related variables toward overall risk classification. Participants reporting symptoms such as abnormal vaginal bleeding, persistent discharge, post-coital bleeding, or pelvic discomfort were substantially more likely to be categorized within elevated-risk groups.

This observation aligns with existing literature emphasizing the importance of symptom recognition in cervical cancer triage and early referral systems (Ghebre et al., 2017). Although symptom-based assessment alone cannot replace formal screening modalities such as Pap smear testing, HPV DNA analysis, or colposcopy, it may still function as an important gateway toward earlier healthcare engagement, particularly in underserved communities where routine screening participation remains limited.

Interestingly, the symptom domain appeared to contribute more strongly than family history variables during multivariate analysis. This may partly reflect the biological reality that cervical cancer is predominantly infection-driven rather than strongly hereditary in the traditional sense. Unlike breast or colorectal cancers, where familial clustering may substantially influence risk prediction models, cervical cancer remains heavily associated with

HPV exposure, reproductive factors, immune status, and healthcare access patterns.

Nevertheless, symptom-based screening approaches also introduce certain limitations. Many gynecological symptoms associated with cervical cancer, including vaginal discharge or pelvic discomfort, are non-specific and may overlap with benign reproductive tract conditions. Consequently, while symptom assessment may increase sensitivity, it may simultaneously reduce specificity and contribute to higher false-positive rates. In community-level preventive systems, however, this trade-off may still be acceptable if the primary objective is early referral rather than definitive diagnosis.

5.4 Relevance of the mHealth Approach in Low-Resource Settings

The integration of the risk assessment model into the *CerviCheck* mHealth platform (Figure 2; Figure 3) represents an important translational component of the study. In recent years, mobile health technologies have increasingly been explored as scalable solutions for healthcare delivery in resource-limited environments. Bangladesh, despite ongoing infrastructural challenges, has experienced rapid expansion in mobile phone accessibility, even among rural populations. This creates an opportunity for digital health interventions capable of bypassing some of the traditional barriers associated with facility-based screening programs.

The culturally adapted and bilingual structure of the application may have contributed meaningfully to participant engagement during field implementation. In many conservative social environments, women often experience discomfort discussing reproductive health concerns directly within formal clinical settings. The relative privacy and autonomy offered by mobile-assisted self-assessment tools may therefore encourage earlier participation and reduce hesitation surrounding sensitive gynecological issues.

Additionally, the non-invasive nature of questionnaire-based assessment likely improved acceptability among women reluctant to undergo conventional cervical examinations. Previous studies have repeatedly highlighted that fear, embarrassment, cultural modesty, and misconceptions regarding gynecological procedures contribute substantially to low screening participation rates in LMIC populations (Rahman et al., 2022). Within this context, a simplified digital triage system may provide an

accessible intermediate step between complete screening avoidance and formal medical evaluation.

Still, it is equally important not to overstate the capability of digital risk assessment platforms. The proposed system should not be interpreted as a replacement for evidence-based cervical cancer diagnostics. Rather, its potential value lies in awareness generation, preliminary risk identification, and referral prioritization within healthcare systems where universal screening infrastructure remains difficult to achieve.

5.5 Comparison With Existing Research and Screening Approaches

The findings of the present study appear generally consistent with prior efforts exploring algorithm-assisted cervical cancer risk prediction and community-level screening support systems. Previous studies utilizing machine learning, decision tree classification, and ensemble prediction models have similarly reported encouraging discriminatory performance in cervical cancer risk assessment (Fernandes et al., 2021; Fatlawi et al., 2022; Wu et al., 2021). However, many of these approaches rely heavily on structured clinical datasets, cytological findings, or imaging-based diagnostic inputs that may not always be feasible within rural or low-resource environments.

In contrast, the current study attempted to prioritize accessibility and contextual practicality over purely computational sophistication. The emphasis on culturally tailored questionnaire design and symptom-guided triage reflects a somewhat different implementation philosophy—one focused less on precision diagnostics and more on scalable community engagement.

Moreover, unlike many purely algorithmic studies, the present work incorporated field-level validation within real-world Bangladeshi communities. This practical deployment component strengthens the translational relevance of the findings, even if the statistical complexity of the model remains comparatively modest.

5.6 Strengths of the Study

Several strengths should be acknowledged. First, the study addressed an important and underexplored healthcare challenge within a low-resource population where cervical cancer screening participation remains suboptimal. Second, the use of community-based recruitment from geographically distinct regions enhanced

the contextual diversity of the cohort. Third, the integration of bilingual educational content and culturally adapted assessment strategies improved usability across varying literacy levels.

Another notable strength lies in the prioritization of sensitivity during model construction. From a preventive oncology perspective, ensuring that potentially high-risk individuals are not overlooked may be particularly important in settings where diagnostic follow-up opportunities remain inconsistent.

Finally, the incorporation of an mHealth platform introduced practical scalability potential. The ability to deploy low-cost preliminary screening support systems through smartphones may hold meaningful implications for future public health outreach initiatives in LMIC settings.

5.7 Limitations of the Study

Despite the encouraging findings, several limitations should be carefully considered. The sample size remained relatively modest, particularly with respect to the number of clinically elevated-risk cases identified during validation. This may have contributed to optimistic performance estimates, including the exceptionally high sensitivity observed in the present analysis.

The study also relied substantially on self-reported questionnaire responses. Variables related to sexual history, reproductive behavior, and symptom reporting may be influenced by recall bias, underreporting, or sociocultural discomfort, particularly within conservative communities. Such biases could potentially affect model accuracy and risk categorization consistency.

Another important limitation is the absence of laboratory-confirmed HPV testing or histopathological verification for all participants. Clinical risk classification was performed by physicians during field screening activities, but definitive diagnostic confirmation was not universally available. Consequently, the model should be interpreted as a preliminary risk stratification framework rather than a validated diagnostic system.

External validation was likewise absent. Although internal cross-validation demonstrated encouraging consistency, larger multicenter studies involving more demographically diverse populations will ultimately be required to determine the broader generalizability and robustness of the model.

5.8 Future Directions and Implications

The findings of this study suggest several important directions for future research. Larger prospective studies incorporating HPV testing, cytological analysis, and longitudinal follow-up would substantially strengthen model validation. Future investigations may also benefit from incorporating machine learning algorithms capable of identifying more complex nonlinear interactions among behavioral, symptomatic, and demographic variables.

There may additionally be value in integrating the proposed framework into broader women's health outreach systems operated through NGOs, rural healthcare workers, or national screening initiatives. In settings where universal cytological screening remains difficult to achieve, digital triage systems could potentially help prioritize women requiring earlier clinical attention.

Ultimately, while the present model remains preliminary, the study highlights a broader and perhaps increasingly important concept: effective cervical cancer prevention in low-resource settings may require not only technological innovation, but also cultural sensitivity, accessibility, and realistic adaptation to community healthcare realities.

6. Conclusion

Cervical cancer prevention in low-resource settings remains deeply challenging, not only because of limited healthcare infrastructure, but also due to cultural barriers, delayed screening behavior, and inadequate public awareness surrounding reproductive health. Within this context, the present study explored whether a culturally tailored, questionnaire-driven mHealth platform could function as a practical early-stage risk assessment tool among Bangladeshi women. The findings demonstrated encouraging screening performance, particularly in terms of sensitivity and overall discriminatory capability, suggesting that structured symptom assessment combined with demographic and behavioral risk profiling may provide meaningful support for preliminary risk stratification.

Importantly, the proposed framework was not intended to replace established diagnostic procedures such as HPV testing, cytology, or colposcopy. Rather, its potential value lies in expanding accessibility, increasing awareness, and identifying women who may benefit from timely clinical evaluation in communities where conventional screening participation remains limited. Although additional multicenter validation involving larger and more diverse populations is still necessary, the study highlights the

growing potential of culturally adapted digital health strategies in strengthening cervical cancer prevention efforts within underserved populations.

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