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Cost-effective screening methods on cervical cancer: A systematic literature review

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Abstract

Background: Cervical cancer is avoidable; yet, it continues to be a significant cause of mortality in low-income and middle-income countries (LMICs) owing to restricted access to screening. Conventional techniques such as Pap smears and HPV DNA testing are efficacious but expensive and challenging to execute in resource-constrained environments. Economical options, like Visual Inspection with Acetic Acid (VIA), HPV self-sampling, and low-cost HPV DNA assays, have arisen to tackle these issues. These strategies are more cost-effective, simpler to use, and have enhanced screening in low- and middle-income countries (LMICs). Nevertheless, obstacles such as quality assurance, post-treatment care, and the expense of novel technology require attention. Ongoing investment and partnership are crucial for enhancing access to these life-saving screening techniques in underserved areas.
Purpose: To explore the cost-effective screening on cervical cancer.
Method: A systematic literature review methodology was utilized to collect and evaluate data from PubMed, Science Direct, and Google Scholar. The terms "cervical cancer screening," "adult women," "pap smear," "HPV vaccination," "behaviour," and "quality of life" were employed for this aim. A total of 131 items were recognized. The investigation included eight papers that met the established criteria. Subsequently, we conduct a systematic analysis and assessment of the selected articles in the existing literature.
Results: Numerous studies have shown that HPV testing, especially self-sampling and screen-and-treat approaches, is more cost-effective and efficient for cervical cancer screening compared to traditional methods such as cytology. In numerous low- and middle-income countries (LMICs), HPV self-sampling combined with thermal ablation has demonstrated an increase in screening coverage, a reduction in cervical cancer incidence, and enhanced treatment outcomes. Cost-effectiveness analyses performed in nations such as China and Brazil demonstrate that transitioning to HPV-based screening methodologies not only decreases expenses but also enhances the early identification of high-grade precancerous lesions. Moreover, self-sampling has proven to be a highly acceptable alternative, considerably enhancing screening participation rates in nations with restricted healthcare access. When integrated with suitable treatment procedures, such as thermal ablation, these methods can significantly diminish cervical cancer incidence, particularly in resource-limited environments.
Conclusion: Economical cervical cancer screening techniques, including VIA, HPV self-sampling, and accessible HPV DNA testing, offer essential solutions to the obstacles encountered by low-income and middle-income countries (LMICs) in the prevention of cervical cancer. These methods are scalable, cost-effective, and efficient in enhancing screening accessibility in situations where conventional procedures are prohibitively expensive or challenging to execute. Nonetheless, obstacles include quality assurance, provision of follow-up care, and management of the expenses associated with new technology must be addressed to facilitate wider use. Ongoing investment and international cooperation are essential for decreasing cervical cancer mortality and guaranteeing that these vital screenings are available to all women.

Keywords: Cervical Cancer; Cost Effective Screening; HPV DNA.

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INTRODUCTION

A persistent infection with high-risk human papillomavirus (HPV) is the primary driving force behind the development of cervical cancer, which is one of the malignancies that can be prevented the most. Despite this, it continues to be the fourth most prevalent cancer in women around the world and a significant contributor to the number of fatalities that are caused by cancer in low- and middle-income countries (LMICs). In the year 2020, the World Health Organisation (WHO) reported that there were approximately an anticipated 604,000 new instances of cervical cancer identified, and there were also approximately 342,000 deaths that occurred (Sekar, Thomas, & Veerabathiran, 2024). Over eighty-five percent of these fatalities took place in low- and middle-income countries (LMICs), which continue to have restricted access to cervical cancer screening and treatment. Because of this dramatic discrepancy between low- and middle-income countries (LMICs) and high-income countries (HICs), there is an urgent need for screening approaches that are accessible, scalable, and cost-effective. These methods should be able to be adopted internationally, particularly in communities with little resources. It is almost always possible to avoid developing cervical cancer by getting vaccinated against the human papillomavirus (HPV) and participating in screening programmes. Both the incidence of cervical cancer and the death rate associated with it have considerably decreased in high-income countries (HICs) as a result of the widespread implementation of Pap smears and HPV DNA testing, in addition to national HPV vaccination programmes. In countries such as Sweden and Finland, for instance, the incidence of cervical cancer have decreased by more than 80 percent. This is mostly attributable to the implementation of organised screening programmes in conjunction with vaccination initiatives (Huang, Zhang, Yin, Zhao, Li, Lu, Zhang, Wu, & Wu, 2024).

In low-income and middle-income countries, however, the widespread adoption of such screening programmes is hampered by a number of obstacles. Traditional techniques of screening, such as the Pap smear, are successful; nevertheless, they are expensive and need a laboratory infrastructure, specialists in the medical field, and several follow-up appointments. When compared to Pap smears, HPV DNA testing is more sensitive; nevertheless, it is even more expensive, costing between $50 and $100 every test. As a result, it is unavailable to many healthcare systems and women living in low- and middle-income countries. Cervical cancer screening has had a limited impact in these places due to the economic, logistical, and infrastructural problems that have presented themselves. As a result, late-stage diagnoses have occurred, which has led to increased mortality rates (Armstrong & Guest, 2020).

In light of the high costs and infrastructure requirements of conventional screening procedures, there is an increasing realisation of the need for alternatives that are both cost-effective and capable of being adopted in low- and middle-income countries (LMICs). It is essential that these approaches be not only economical but also easily accessible and capable of being incorporated into pre-existing healthcare systems. This is especially important in rural areas, where the infrastructure for healthcare is limited. A number of intriguing solutions to these issues have emerged, including Visual Inspection with Acetic Acid (VIA), HPV self-sampling, and cheap HPV DNA testing devices. The use of these methods provides alternatives to conventional screening that are scalable and inexpensive, and they have the potential to greatly lessen the burden of cervical cancer in low-income and middle-income countries (Rasmussen, Hoffman, Phiri, Makwaya, Kominski, Bastani, Moses, & Moucheraud, 2024).

It has been demonstrated that immunisation against HPV can significantly cut the number of cases of cervical cancer; nevertheless, the coverage of these vaccination programmes is still poor in many low- and middle-income countries. There are a number of factors that contribute to the poor uptake, including cultural hurdles, misinformation, and a lack of access to healthcare services. In order to promote knowledge about the significance of HPV vaccination and screening, it is required to conduct research on community-based education programmes that are sensitive to different cultures and geared to educate people about such programmes. In addition, there is a want for additional research regarding the cost-effectiveness of integrating HPV vaccination with screening programmes, particularly in countries that have limited resources. The viability of these programmes over the long term has been the subject of a limited amount of research, despite the fact that

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cost-effective screening tools such as VIA and HPV self-sampling have demonstrated their possibility. The majority of nations do not have sufficient data regarding how to include these screening approaches into their national healthcare systems and how to educate healthcare staff in order to guarantee accurate results and appropriate follow-up care. It is necessary to conduct additional study in order to investigate the most effective methods for expanding these programmes on a national scale and making sure that follow-up care is easily available and economically feasible for women who test positive (Bains, Choi, Soldan, & Jit, 2019).

VIA, HPV self-sampling, and HPV DNA testing are all promising approaches; however, there is a dearth of comprehensive comparative studies that evaluate the efficiency of these procedures in a variety of settings. In order to assist policymakers in picking the screening approach that is best suitable for their respective nations, it would be beneficial to do research that compares the cost-effectiveness, sensitivity, and specificity of these methods in a variety of healthcare settings and populations. Furthermore, it is essential to do research that investigates the acceptability of these procedures among various cultural groups in order to guarantee high participation rates in screening programmes. By giving women access to self-sampling kits, instructional resources, and follow-up treatment through mobile platforms, mobile health (mHealth) technology has the potential to revolutionise cervical cancer screening in low-income and middle-income countries (LMICs) (Paulauskiene, Stelemekas, Ivanauskiene, & Petkeviciene, 2019). On the other hand, there is a paucity of studies on the efficacy of mobile health solutions for cervical cancer screening, particularly in rural locations where access to mobile devices may be restricted. In order to get significant insights into the future of cervical cancer prevention, studies that evaluate the feasibility of using mobile health platforms to deliver HPV self-sampling kits and guide women through the screening procedure could be conducted. There are significant concerns around intellectual property (IP) rights and royalties that have been brought to light by the development and widespread use of screening methods that are both cost-effective and detect cervical cancer. Several of the more recent HPV DNA testing platforms and self-sampling kits are examples of private technology. These technologies are protected by patents that are held by research organisations or pharmaceutical corporations. For instance, commercial businesses have developed platforms such as GeneXpert; however, the broad application of these technologies in low- and middle-income countries (LMICs) may be limited due to the expenses associated with patents, which in turn restricts the affordability and accessibility of these technologies (Tran, Hathaway, Broshkevitch, Palanee-Phillips, Barnabas, Rao,, & Sharma, 2024).

In low-income and middle-income countries (LMICs), where healthcare expenditures are limited, patents and intellectual property rights related with HPV vaccinations and testing technology can create major barriers to access. For the purpose of increasing access to cervical cancer screening, it will be essential to either ensure that generic versions of these technologies are available at a price that is cheap or that licencing arrangements enable for production at a low cost. In order to guarantee that screening procedures that are both cost-effective and efficient may be applied on a large scale, international health organisations and governments need to establish licencing agreements that do not require royalty payments or licencing models that have lower costs. Open-access solutions are also becoming increasingly popular in the field of cervical cancer prevention, which is another area of concentration (Aarnio, Östensson, Olovsson, Gustavsson, & Gyllensten, 2020). A number of research organisations are currently working on the development of screening technologies that are not trademarked and can be freely adopted by nations that have limited resources by those nations. As an illustration, certain academics are working on the development of low-cost, open-access HPV testing kits that may be manufactured locally in low- and middle-income countries (LMICs), thereby reducing reliance on costly technologies that are imported. One of the most important things that might be done to increase the availability of screening technologies that are cost-effective is to encourage innovation in this area that is driven by public health (Defo & Domgue, 2020). Royalty agreements between pharmaceutical companies and governments can also provide a cash stream for the purpose of funding additional research into the prevention of cervical cancer. These agreements pertain to screening technologies that have been produced for commercial use.

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Nevertheless, it is of the utmost importance that these agreements be structured in a manner that guarantees low-income and middle-income countries (LMICs) inexpensive access to screening technologies. Governments and international organisations need to collaborate in order to find a middle ground that allows for the promotion of innovation while also ensuring that screening technologies are provided at prices that are affordable for widespread application (Hafidz, Icanervilia, Rizal, Listiani, Setyaningsih, Sasanti, Ekawati, Atthobari, Utami, Trirahmanto, Tjokroprawiro, Harsono, Masytoh, Haryani, Subekti, & Nadjib, 2024).

In spite of the fact that cost-effective screening methods have demonstrated a great deal of potential, there are still a number of obstacles that need to be overcome in order to guarantee their success over the long run. The problems that need to be addressed include ensuring that screening programmes have sustainable funding, overcoming cultural obstacles that prevent women from participating, and expanding screening programmes on a national scale to reach all women who are at risk. As a result of the COVID-19 pandemic, numerous cervical cancer screening programmes have been disrupted, particularly in low- and middle-income countries (LMICs). This highlights the necessity of resilient healthcare systems that are able to continue providing important services even in the midst of global health crises. In the future, there is a need for additional research into the efficiency of these screening approaches over the long term, particularly with regard to the influence they have on cervical cancer (Yusransyah, Kristina, Endarti, & Trung, 2023).

RESEARCH METHOD

The current work employed the specified reporting items for systematic literature reviews and selected articles in accordance with the PRISMA guidelines. This was done in order to conduct a systematic review. Through our enquiry, scholarly publications concerning the screening of cervical cancer that is both cost-effective and efficient were uncovered. In the course of our research, we conducted a thorough search of the existing literature, making use of the particular phrases "cost-effectiveness screening on cervical cancer," "adult women," and/or "pap smear," and/or "HPV vaccination," and/or "behaviour," and/or "Quality of life."

The PICOS framework was utilised while this study was in the process of creating the criteria. S represents the study design, which may be longitudinal, cross-sectional, Markov model, case-control, or cohort. P represents the population, specifically cervical cancer; I represents an intervention in the form of screening; C represents a comparison or comparison group that does not use comparison; O represents the outcome, specifically cost-effective screening on cervical cancer; and S represents the characteristics of the study design.

For the aim of our analysis, we extracted data from the publications in an independent manner, paying particular attention to the author, the study design, the purpose, and the sample. The search for articles produced a total of 131 items, which were dispersed throughout 59 journals published in PubMed, 49 journals published on Google Scholar, and 23 collections published on Science Direct. After that, we got eight articles that were informative and useful. In this study, the current state of the most recent screening technologies that are both effective and cost-efficient against cervical cancer is discussed. These technologies are available to the public.

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RESEARCH RESULTS

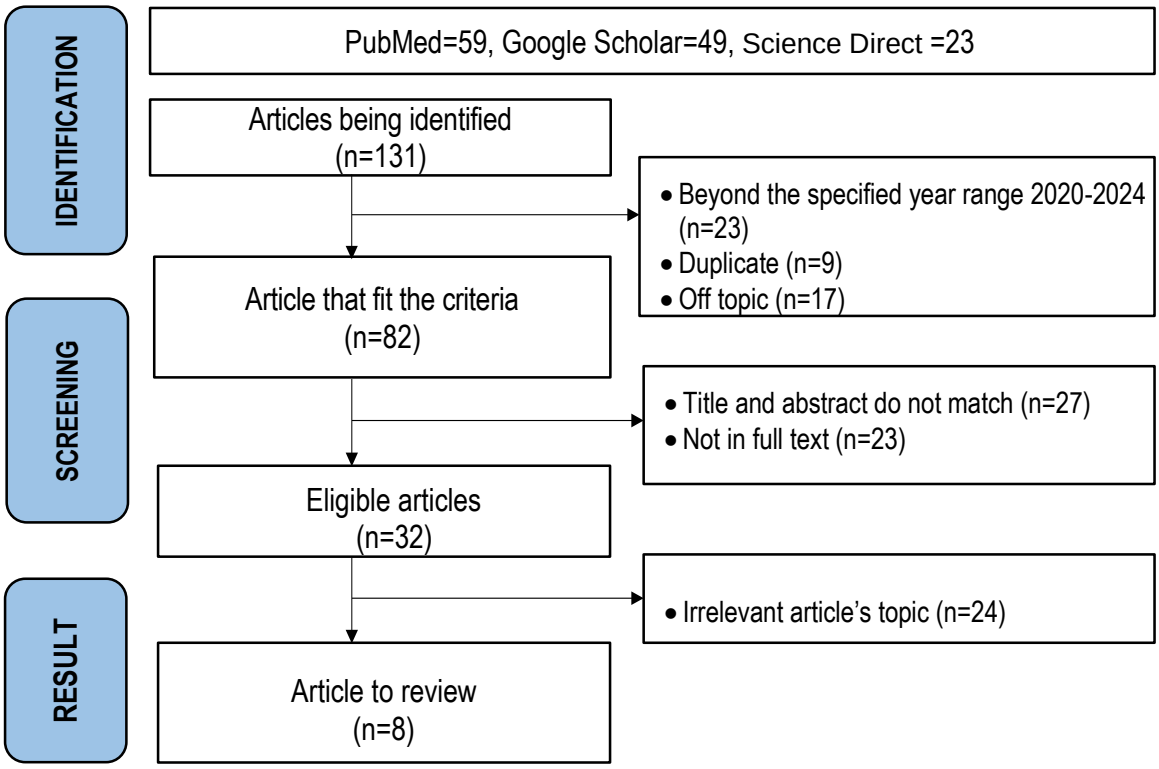

Figure 1: PRISMA Flow Diagram

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Table 1. The Main Characteristics of Included Studies

(Author, Year) (Country)	Purpose	Method	Results
(Shen et al., 2023) (China)	Assess the cost-effectiveness of AI-assisted liquid-based cytology (LBC) testing in comparison to manual LBC and HPV-DNA testing for primary cervical cancer screening in China.	We constructed a Markov model for a cohort of 100,000 women aged 30 years to mimic the lifetime course of cervical cancer. We assessed the incremental cost-effectiveness ratios (ICER) of 18 screening strategies, comprising three screening techniques and six screening frequencies, from the perspective of a healthcare provider. The willingness-to-pay level (US$30,828) was established at three times the per capita gross domestic output of China in 2019. Univariate and probabilistic sensitivity analyses were conducted to assess the robustness of the findings.	In comparison to no screening, all 18 screening modalities demonstrated cost-effectiveness, with an incremental cost-effectiveness ratio (ICER) ranging from $622 to $24,482 per quality-adjusted life-year (QALY) gained. If HPV testing, following the implementation of population-level screening, costs $10.80 or more, then screening every five years with AI-assisted LBC would represent the most cost-effective approach, yielding an ICER of $8790 per QALY gained in comparison to the less expensive non-dominated method on the cost-effectiveness frontier. The likelihood of it being cost-effective was greater (55.4%) than that of alternative alternatives. Sensitivity analysis indicated that the most cost-effective strategy would transition to AI-assisted LBC testing every three years if both the sensitivity (74.1%) and specificity (95.6%) of this method were diminished by ≥10%. The most economical approach would be HPV-DNA testing every five years if the expense of AI-assisted LBC exceeds that of manual LBC or if the cost of the HPV-DNA test is marginally decreased (from $10.8 to below $9.4).
(Palmer et al., 2024) (Japan)	Assessed the cost-effectiveness of cervical cancer screening methodologies in conjunction with universal nonavalent	A cost-effectiveness analysis was conducted utilising an age-specific Markov microsimulation model for Japan to assess total costs, quality-adjusted life-years (QALYs) acquired, incremental cost-effectiveness ratios (ICER), colposcopies, biopsies, and treatments for precancerous conditions and cervical cancer	In comparison to traditional cytology, the assessed techniques would result in an increased expenditure of US$839,280–738,182,669 and yield 62,755–247,347 quality-adjusted life years. HPV testing that differentiates HPV16/18 with reflex liquid-based cytology (every three years) would be the most cost-effective option (ICER = US$7511 per QALY gained). At a willingness-to-pay (WTP) of one times gross domestic product (GDP) per capita, the

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(Author, Year) (Country)	Purpose	Method	Results
	HPV vaccination for girls aged 12 to 16 years.	across 29 integrated vaccination and screening strategies (conventional cytology, liquid-based cytology (LBC), HPV testing, and HPV self-collection). A cohort of 100,000 girls aged 12 to 16 years was administered the nonavalent HPV vaccine across their lifetime, with current vaccination coverage at 0.08% and current screening coverage at 43.7%. A discount rate of 3% was utilised for costs and QALYs. Univariate and probabilistic sensitivity analyses were conducted to evaluate the robustness of the findings. Expenses were documented in United States dollars (2023).	likelihood of cost-effectiveness was 70%. At historically elevated vaccination coverage (70%), ICERs diminished overall but did not alter the hierarchy of the most cost-effective option. A 5-year interval proved to be more cost-effective than a 3-year interval. The inclusion of HPV self-collection for under-screened women enhanced the cost-effectiveness of all regimens.
(Knauss et al., 2023) (Norway)	Evaluated the cost-effectiveness of dispatching a human papillomavirus self-sampling (HPV-ss) kit, either directly or through an invitation to request, in comparison to sending reminder letters to long-term non-attenders in Norway.	The research performed a secondary analysis utilising data from the Equalscreen project, which involved 6,000 women aged 35 to 69 years who had not undergone screening in over 10 years. Participants were randomly assigned to three groups: reminder letter (control); invitation to request HPV-ss kit (opt-in); and direct mailing of HPV-ss kit (send-to-all). Cost-effectiveness (2020 Great British Pounds (GBP)) was assessed using incremental cost-effectiveness ratios (ICERs) per additional tested woman and per additional cervical intraepithelial neoplasia grade 2 or worse (CIN2+) from both extended and direct healthcare perspectives.	Participation, CIN2+ detection, and overall screening expenses were greatest in the send-to-all group, succeeded by the opt-in and control groups. Non-histological medical appointments accounted for 67% of the total expenses in the control group and < 31% in the self-sampling groups. From a comprehensive healthcare viewpoint, the ICERs were 135 GBP and 169 GBP every additional screened woman, and 2864 GBP and 4165 GBP per additional CIN2+ detected for the opt-in and send-to-all strategies, respectively.

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(Author, Year) (Country)	Purpose	Method	Results
(Zhao et al., 2023) (China)	Evaluated the cost-effectiveness of their integrated approach to guide accessible, inexpensive, and acceptable cervical cancer preventive methods.	The research established a hybrid model to assess costs, health outcomes, and incremental cost-effectiveness ratios (ICER) of six screen-and-treat strategies that integrate HPV testing (self-sampling or physician-sampling), triage methods (HPV genotyping, colposcopy, or none), and thermal ablation, from a societal viewpoint. An initial cohort of 100,000 females born in 2015 was identified for consideration. Strategies with an Incremental Cost-Effectiveness Ratio (ICER) below the Chinese gross domestic product (GDP) per capita ($10,350) were deemed extremely cost-effective.	In comparison to existing techniques in China (physician-HPV with genotyping or cytology triage), all screen-and-treat strategies are cost-effective, with self-HPV without triage being optimum, yielding the highest additional quality-adjusted life-years (QALYs) gained (220 to 440) in both rural and urban areas of China. Every screen-and-treat technique utilising self-collected samples is economically advantageous compared to existing methods (−$818,430 to −$3540), while physician-collected samples result in higher expenses relative to current physician-HPV with genotype triage (+$20,840 to +$182,840). In screen-and-treat techniques devoid of triage, expenditures (+$9,404 to +$380,217) would be allocated to the screening and treatment of precancerous lesions rather than to cancer therapy, in contrast to existing screening strategies. Significantly, approximately 81.6% of HPV-positive women would have overtreatment. When triaged with HPV 7 types or HPV16/18 genotypes, 79.1% or 67.2% (respectively) of HPV-positive women would experience overtreatment, resulting in the avoidance of just 19 or 69 cancer cases.
(Simms et al., 2023) (WHO)	Assess the effects of seven principal screening scenarios in 78 low-income and lower-middle-income countries (LMICs) on the general female population.	In 2020, the World Health Organisation (WHO) initiated a strategy to eradicate cervical cancer as a public health issue. The WHO issued revised cervical screening guidelines in 2021 to bolster the plan. This update utilises the proven modelling platform, Policy1-Cervix, to assess the effects of seven primary screening scenarios across 78 low-income and lower-middle-income	With an assumed coverage of 70%, we determined that primary human papillomavirus (HPV) screening methods were the most efficacious and economically viable, decreasing age-standardized mortality rates from cervical cancer by 63–67% when administered every 5 years. Strategies that involve triaging women prior to treatment (utilising 16/18 genotyping, cytology, visual inspection with acetic acid (VIA), or colposcopy) shown comparable effectiveness to HPV screening without triage, while resulting in fewer pre-cancer interventions. Screening via VIA or cytology every

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(Author, Year) (Country)	Purpose	Method	Results
		countries (LMICs) for the overall female population.	three years shown to be less effective and less cost-efficient than HPV screening conducted every five years. Moreover, VIA produced about twice the quantity of pre-cancer interventions in comparison to HPV.
(Nguyen et al., 2022) (Papua New Guinea)	assessed the efficacy, cost-efficiency, and resource ramifications of a countrywide cervical screening initiative utilising self-collected HPV S&T in comparison to VIA in PNG.	An extensively validated platform ('Policy1-Cervix') was calibrated for PNG. A total of 38 techniques were chosen for analysis, encompassing changes in age ranges and screening frequencies, hence facilitating the discovery of the ideal strategy among several alternatives. A compilation of solutions deemed most effective and cost-efficient was thereafter chosen for additional analysis regarding long-term outcomes and budgetary impact assessment. In the baseline scenario, we posited that primary HPV testing exhibits a sensitivity of 91.8% for cervical intraepithelial neoplasia 2 (CIN2+) and that primary VIA has a sensitivity of 51.5%, derived from our previous field study and corroborated by existing literature. We prudently estimated the cost of HPV sample and testing to be US$18. Costs were assessed from the perspective of the service provider, utilising data from regional field trials and local consultations.	Self-collected HPV screening and testing was more effective and more cost-efficient than visual inspection with acetic acid (VIA). Collecting HPV self-samples twice or thrice over a lifetime would be cost-effective at 0.5 times the gross domestic product (GDP) per capita (incremental cost-effectiveness ratio: US$460–US$656 per life-year saved; 1 GDP per capita: US$2829 or PGK9446 as of 2019) and could avert 33,000 to 42,000 cases and 23,000 to 29,000 deaths in Papua New Guinea over the next 50 years, provided that coverage reaches 70% from 2023 onward.

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(Author, Year) (Country)	Purpose	Method	Results
(Chauhan et al., 2020) (India)	Evaluate the cost-effectiveness of several screening systems for cervical cancer and human papillomavirus (HPV) vaccine in India.	A Markov model grounded in a societal perspective was developed to assess the lifetime costs and outcomes of screening (utilising either visual inspection with acetic acid (VIA), the Papanicolaou test, or HPV DNA testing at various intervals) in a hypothetical cohort of women aged 30 to 65 years or vaccination among adolescent girls. The diagnostic accuracy of screening techniques, the efficacy of HPV vaccination, and transition probability statistics were derived from current meta-analyses. Primary data was gathered to evaluate the per capita cost of screening, the expense of cervical cancer treatment, and quality of life.	The use of various screening procedures results in a decrease in the lifetime incidence of cervical cancer cases attributable to HPV 16/18 from 20% to 61%, and cervical cancer mortality from 28% to 70%, relative to the absence of screening. Among the numerous screening procedures, conducting Visual Inspection with Acetic Acid (VIA) every five years and every ten years shown to be cost-effective at one-time per capita GDP, with the five-year interval yielding more health benefits than the ten-year interval. Therefore, implementing VIA screening every five years at an additional cost of US$ 829 (INR 54,881) per QALY gained is the advised approach for India. Moreover, concerning HPV vaccination, it results in a 60% decrease in cancer cases and mortality associated with HPV 16/18 compared to the absence of vaccination. Furthermore, when this vaccinated group of adolescent females undergoes screening later in life (with VIA every 10 years and VIA every 5 years), it results in a 69%-76% decrease in cancer incidence and a 71%-81% reduction in cancer mortality. In comparison to the absence of vaccination and screening, both HPV vaccination alone and the combination of vaccination with screening (utilising VIA every 5 years and VIA every 10 years) demonstrate cost-effectiveness, with ICERs ranging from US$ 86 (INR 5,693) to US$ 476 (INR 31,511) per QALY gained. Ultimately, when the cohort of adolescent girls vaccinated against HPV reaches 30 years of age, the frequency of screening with with should be established according to the vaccination coverage within that cohort.

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(Author, Year) (Country)	Purpose	Method	Results
(Vale et al., 2021) (Italy)	To provide a modelling research utilising local healthcare expenditures and epidemiological data from a population-based programme to evaluate the cost-effectiveness of implementing hrHPV testing.	A cost-effectiveness analysis utilising a microsimulation dynamic Markov model. The facts and costs were derived from local sources and a literature review. The location was Indaiatuba, Brazil, which has implemented the hrHPV test instead of cytology since 2017. Following the calibration of the model, one million women were simulated inside hypothetical cohorts. Three strategies were evaluated: cytology for women aged 25 to 64 every three years; hrHPV testing for women aged 25 to 64 every five years; and a hybrid strategy comprising cytology for women aged 25 to 29 every three years and hrHPV testing for women aged 30 to 64 every five years. The outcomes measured were Quality-Adjusted Life Years (QALY) and Incremental Cost-Effectiveness Ratio (ICER).	The hrHPV testing and the hybrid technique were the predominant approaches. The costs were reduced, yielding a more efficient alternative with a negative incremental ratio of US$ 37.87 for the hybrid strategy and negative US$ 6.16 for the HPV method per QALY gained. A reduction in treatment costs would lead to a decrease in ICER, while an increase in the costs of the hrHPV test would result in a rise in ICER.

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DISCUSSION

Cervical cancer remains to be one of the most preventable kinds of cancer; nonetheless, it disproportionately affects women in low-income and middle-income countries (LMICs), which are nations with inadequate access to healthcare and where preventative interventions are frequently unavailable. Traditional screening approaches, albeit being effective in high-income countries (HICs), are difficult to execute in settings with limited resources due to the financial and logistical challenges involved (Gossa & Fetters, 2020). The development of screening technologies that are both cost-effective and adapted to low-income and middle-income countries (LMICs) constitutes a significant step forward in the fight against cervical cancer. Nevertheless, in spite of these improvements, there are still substantial issues that need to be solved in order to guarantee the successful deployment of these methods and their continued viability across time (Casas et al., 2022).

In nations where it is extensively used, the Pap smear, which has traditionally been considered the gold standard for cervical cancer screening, has proven to be extremely effective in lowering the average number of cases of cervical cancer. Screening programmes that are based on Pap smears have been shown to reduce the incidence of cervical cancer by as much as 80 percent in countries such as the United States and Finland. In low-income and middle-income countries (LMICs), however, the infrastructure that is necessary to support Pap smear screening is frequently missing. This infrastructure includes cytology labs, trained healthcare staff, and logistical support for follow-up treatment. Furthermore, the cost of Pap smears, which can vary from $25 to $50 in high-income countries, makes routine screening inaccessible to a significant number of women in low- and middle-income countries (LMICs) (Devine, Vahanian, Sawadogo, Zan, Bocoum, Kelly, Gilham, Nagot, Ong, Legood, Meda, Miners, & Mayaud, 2021). In these countries, healthcare funds are restricted, and patients may be dissuaded from seeking preventive care due to the high out-of-pocket costs. In addition, although HPV DNA testing yields a higher level of sensitivity in comparison to Pap smears, it is even more prohibitively expensive in contexts where resources are limited. The price of a single HPV DNA test can reach as high as one hundred dollars, and the fact that such a test requires sophisticated laboratory infrastructure in order to analyse the results renders its utilisation in rural regions impracticable. Therefore, in order to guarantee that women living in low-income and middle-income countries have access to regular cervical cancer screening, it is necessary to develop alternative screening technologies that are less expensive, simpler to administer, and scalable to large populations (Sun, Patel, Fiorina, Glass, Rochaix, Foss, Legood, Bardou, Andersen, Kirkegaard, Bøje, Tranberg, McKee, Bell, Greenley, Rigby, Rossi, Ghirottoo, Bartolini, & Dascher-Nadel, 2024).

The development of screening procedures that are both cost-effective and cheap, such as Visual Inspection with Acetic Acid (VIA), HPV self-sampling, and affordable HPV DNA testing platforms, has opened a realistic road ahead for the prevention of cervical cancer in low-income and middle-income countries (LMICs). Through the reduction of expenses, the simplification of administration, and the improvement of accessibility in rural and disadvantaged areas, these methods solve a significant number of the challenges that are connected with traditional screening procedures (Tsiachristas, Gittins, Kitchener, & Gray, 2018).

VIA has become one of the most extensively utilised low-cost screening procedures in low-income and middle-income countries (LMICs) due to the fact that it is both simple and affordable. During a VIA, diluted acetic acid, often known as vinegar, is applied to the cervix, and the cervix is visually examined for abnormalities that appear white when exposed to the acid (Fernandes, Meng, Juliet, Raimond, Rao, Rubeena, Tamilarasi, Evangelin, & Mathew, 2022). It is possible for healthcare providers to do the test with only a small amount of training, it does not require any laboratory infrastructure, and it costs less than one dollar each test. The fact that this is the case makes VIA an excellent screening approach for environments with low resources. VIA has been demonstrated to have a sensitivity of 67-79% and a specificity of 85-94%, making it comparable to Pap smears in terms of its ability to detect precancerous lesions from a clinical standpoint (Burger, Sy, Nygard, & Kim, 2017). In countries such as India, where large-scale screening programmes have been effectively implemented, women in rural areas who previously

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did not have access to cervical cancer screening have been able to receive screening. For instance, a VIA-based screening programme in the Indian state of Maharashtra had the effect of increasing screening coverage from 6% to 30% in its first year of operation. In addition, a study that was conducted over a period of twelve years in rural India discovered that VIA screening resulted in a thirty percent decrease in the cervical cancer mortality rate. Despite the fact that it has many benefits, VIA is not devoid of difficulties (Sengupta, Pal, Samaddar, Samaddar, & Goswami, 2024). Due to the fact that the accuracy of the test is strongly dependent on the expertise and experience of the healthcare worker who is performing the inspection, there is also the possibility of false positives, which might result in follow-up treatments that are not necessary. Furthermore, it is still a challenge in many contexts to ensure that women who have abnormal results receive treatment in a timely manner. This is especially true in rural areas, where there are less and fewer healthcare facilities. Via, on the other hand, has been demonstrated to be an efficient and scalable strategy for boosting screening coverage in low-income and middle-income countries (Jeyakumar & Mohanapu, 2019).

The use of HPV self-sampling presents yet another promising alternative to the conventional screening approaches that are performed in clinics. With this technique, women are able to collect their own cervical samples by using a swab or brush. These samples are then analysed to determine whether or not they contain high-risk HPV strains. In situations when women are unable to attend clinics for routine screening due to cultural barriers or logistical obstacles, self-sampling has been found to be extremely acceptable to women and leads to higher participation in screening programmes. This is especially true in circumstances where women lack the ability to attend clinics. In terms of advantages, the convenience of self-sampling is among the most significant advantages. In order to eliminate the need for women to visit clinics, it is possible for them to collect samples at home or in community settings (Jeyakumar & Mohanapu, 2019). This has the potential to reduce the stigma that is associated with gynaecological examinations. Studies conducted in countries such as Mexico and Vietnam have indicated that self-sampling is an effective method for boosting the number of people who undergo screening. In Mexico, for instance, the provision of self-sampling kits resulted in a thirty percent rise in the number of women who participated in screening programmes. This was especially true for women who had never been checked previously. There is also the possibility that self-sampling might be used to reach underserved populations in rural and distant areas, which have restricted access to healthcare institutions. Additionally, the cost of self-sampling kits has fallen, with some kits being available for less than ten dollars each test. This has made it a more accessible choice for low- and middle-income countries. However, there are still obstacles to overcome in order to guarantee that women who test positive for HPV receive follow-up care, and additional study is required to evaluate whether or not self-sampling programmes in low- and middle-income countries can be maintained over the long term (Hariprasad, Bagepally, Kumar, Pradhan, Gurung, Tamang, & Bhatnagar, 2024).

There have been recent developments in technology that have led to the creation of affordable HPV DNA testing platforms. One example of such a platform is GeneXpert, which offers HPV testing that is both quick and accurate at a fraction of the cost of older procedures. There is a reduction in the requirement for women to travel large distances in order to get screening services because GeneXpert tests can be performed in decentralised settings such as community health centres when they are administered (Lew, Feletto, Wade, Caruana, Kang, Nickson, Simms, Procopio, Taylor, Worthington, Smith, & Canfell, 2019). This test, which costs roughly twenty dollars per test, is substantially more economical than the conventional HPV DNA testing that is currently available. Additionally, it provides a scalable option for nations that have limited resources. In spite of the fact that GeneXpert has demonstrated some degree of potential, it is still rather expensive in comparison to VIA. Efforts are currently being made to further reduce the cost and to broaden access to a greater number of nations. In addition, there is a requirement for public-private partnerships to offer assistance in the widespread implementation of HPV DNA testing platforms that are inexpensive in low-income and middle-income countries (Ma, Wang, Gao, Dai, Zhang, Wang, Wang, Wang, Jiang, Jing, Yang, Zhao, Lang, & Qiao, 2019).

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A viable option for expanding cervical cancer screening in low- and middle-income countries (LMICs) is also emerging in the form of mobile health (mHealth) technologies. The delivery of educational resources, the tracking of screening participation, and the guiding of women through the screening process, including the utilisation of HPV self-sampling kits, are all possible applications of mobile health computing platforms (Tantitamit, Khemapech, Havanond, & Termrungruanglert, 2020). It has been demonstrated through research that mobile health interventions have the potential to enhance screening participation, particularly in rural areas where access to healthcare is restricted. The distribution and utilisation of HPV self-sampling kits in rural locations have been monitored through the use of mobile health platforms. This has enabled women to receive follow-up care in the event that they test positive for the virus. Despite the fact that mobile health has a huge potential to improve cervical cancer screening coverage, additional research is required to identify whether or not these technologies are feasible and whether or not they are beneficial in cultural and healthcare settings that are different from one another (Yusuf, 2024). Despite the fact that cost-effective screening methods have shown a great deal of potential, there are still a number of obstacles that need to be overcome in order to guarantee their continued success and viability over the long journey. The cultural stigma that is associated with reproductive health is one of the most major obstacles that prevents low-income and middle-income countries from screening for cervical cancer. In many parts of the world, women are reluctant to get screened because they are afraid of being judged or stigmatised for seeking gynaecological care during their reproductive years (Ratushnyak, Hoogendoorn, & van Baal, 2019). The fact that discussions concerning sexual health are considered taboo is especially prevalent among groups that are considered to be conservative. The implementation of educational efforts that are sensitive to different cultures and are geared towards addressing these issues is absolutely necessary in order to increase participation in screening programmes. Studies have demonstrated that community-based education programmes that include participation from local leaders and healthcare professionals have the potential to be helpful in lowering stigma and increasing the number of people who get screened (Ruff, Harper, Dalton, & Fendrick, 2023).

Another important problem is making certain that the screening procedures are of a high quality and consistent throughout. When it comes to techniques such as the VIA, the accuracy of the test is greatly dependent on the levels of expertise and experience possessed by the healthcare practitioner who is conducting the examination. In many low-income and middle-income countries (LMICs), there is a dearth of qualified healthcare staff. In order to guarantee that screening results are reliable, continual training programmes are required. In addition, it is a significant issue to ensure that women who test positive for human papillomavirus (HPV) or atypical lesions receive timely follow-up care and treatment (Aoki, Yin, Li, Bhatla, Singhal, Ocviyanti, Saika, Suh, Kim, & Termrungruanglert, 2020). This is especially true in rural regions, where there are an inadequate number of healthcare facilities. Although cost-effective screening methods are more economical than traditional screening methods, they nevertheless require continued financing to maintain their long-term sustainability. This is because they are more likely to be successful. A collaborative effort between governments, international health organisations, and donors is required in order to guarantee that screening programmes receive sufficient funding and that women have access to follow-up care that is within their financial means. The expansion of these programmes to include all women who are at risk will necessitate a substantial investment in both the infrastructure of healthcare and the human resources available for provision of healthcare (Parra, Oden, Schmeler, & Richards-Kortum, 2019). Another obstacle to overcome is the problem of intellectual property (IP) rights and royalties that are connected to more recent HPV testing platforms. Commercial enterprises are responsible for the development of many of the more advanced HPV testing platforms. The expenses involved with patents and royalties can make it difficult for low-income and middle-income countries to gain access to these technologies. The negotiation of royalty-free licencing agreements or the development of open-access inventions that can be freely adopted by countries with low resources will be essential in order to guarantee that screening methods that are cost-effective are available to everyone (Shastri, Temin, Almonte, Basu, Campos,

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Gravitt, Gupta, Lombe, Murillo, Nakisige, Ogilvie, Pinder, Poli, Qiao, Woo, & Jeronimo, 2022).

CONCLUSION

There has been a significant advancement in the fight against cervical cancer in low-income and middle-income countries (LMICs) as a result of the development of cost-effective cervical cancer screening technologies. These methods include VIA, HPV self-sampling, affordable HPV DNA testing platforms, and modern health solutions. A significant number of the challenges that are associated with conventional screening procedures are addressed by these methods, which provide solutions that are scalable, inexpensive, and can be customised to meet the particular requirements of settings with limited resources.

Nevertheless, there are still plenty of obstacles to overcome in order to guarantee the quality, longevity, and accessibility of these screening technologies. In order to ensure that these approaches can be successfully applied on a broad scale, it is necessary to address a number of issues, including cultural obstacles, quality assurance, cost, and intellectual property rights requirements. For the purpose of preventing cervical cancer, it is imperative that governments, international health organisations, and donors collaborate in order to guarantee that women living in low-income and middle-income countries have access to the screening and follow-up care they require. As long as the global health community continues to innovate and invest in these technologies, it will be possible to drastically lower the incidence of cervical cancer and the fatality rate associated with it, which will ultimately save millions of lives. On the other hand, in order to accomplish this objective, it will be necessary to conduct ongoing research, make investments, and work together in order to guarantee that screening procedures that are both affordable and accessible to all women, regardless of their location or economic standing.

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