Gynecologic Oncology Reports 45 (2023) 101130

Contents lists available at ScienceDirect

Gynecologic Oncology Reports

journal homepage: www.elsevier.com/locate/gynor

Digital cervicography for cervical cancer screening in low-resource settings: A scoping review

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ARTICLE INFO

Keywords:
Cervical cancer
Cancer prevention
Cancer screening
Digital cervicography
mHealth

ABSTRACT

Introduction: Digital cervicography (DC) is a method of capturing images for analysis during visual inspection with acetic acid (VIA) for cervical cancer screening. Cervical cancer is the 3rd leading cause of female cancer in the world with approximately 90 % of deaths due to cervical cancer occurring in low and middle income countries (LMICs). The need for cost-effective and sustainable methods for screening is vital in these settings. This scoping review systematically synthesizes published data illustrating the use of DC in screening programs. We aim to understand how digital cervicography is used, implemented, and impacted on programs.
Methods: Search of eight online databases identified 53 studies published between 1993 and 2021. Inclusion of articles were English language, cervical cancer screening program located in an LMIC, and DC as an intervention.
Results: All studies were cross-sectional studies (n = 53), with variation in terminology, uses, and device methods. Devices were grouped as either smartphones (n = 14), commercially available digital cameras (n = 17), or other (EVA®, n = 4; Cerviscope, n = 12; custom device, n = 4; or not specified, n = 2). Nineteen studies found acceptability and feasibility for DC in their screening programs. Various programs using DC found benefits such as task sharing, healthcare worker training, patient education and using images for review from a remote specialist or mentor.
Conclusion: The use of DC in LMICs is beneficial for support of healthcare workers, enhances quality improvement and demonstrates overall acceptability in screening programs. Advancing technologies for human papillomavirus (HPV) testing and cytology are common methods for cervical cancer screening, although are limited in LMICs. This scoping review demonstrates the different methods, uses, and benefit of digital cervicography in cervical cancer screening programs.

1. Introduction

1.1. Background

Cervical cancer is the second most common in females aged 15–44 worldwide with 604,127 new cancer cases diagnosed in 2020. The heaviest burden of disease is in low- and middle-income countries (LMICs) due to many barriers such as access to early screening and treatment (Bruni et al., 2021). As a result, many women present with high grade cervical dysplasia or are already found to be cancerous with metastasis. Up to 80 % of these advanced cases are found in LMICs. Common barriers include lack of healthcare infrastructure, access to non-surgical treatment modalities, chronic shortages of health workers and training resources, referral processes and inadequate health information systems making it difficult to track individual patients or monitor program performance (Parham et al., 2015; Campos et al., 2017).

Cervical cancer screening differs widely between countries and includes methods such as cervical smear (pap smear) for cytology evaluation; testing for the presence of human papillomavirus (HPV), the causative agent of > 70 % of cervical cancers; visual inspection with acetic acid (VIA); or various combinations of these. High-resource countries have adopted cytology and HPV testing as routine screening every three to five years; although in many LMICs, it is not performed routinely due to dependency on trained specialists, resources, and high cost of equipment (Cubie and Campbell, 2020).

In low-resource settings, without cytology or HPV testing capability, the WHO recommends VIA as a screening method which can be

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https://doi.org/10.1016/j.gore.2022.101130
Received 20 September 2022; Received in revised form 20 December 2022; Accepted 23 December 2022
Available online 4 January 2023

performed by a trained healthcare worker (HCW) using 3–5 % acetic acid applied to the cervix and interpretation of cervical changes after application. This method can be a relatively inexpensive option since supplies can be locally sourced and the "same-day see-and-treat" approach can be employed based on immediate results. This method can be followed with visual inspection with Lugol's iodine (VILI) and is more sensitive and similarly specific, but it requires products not as accessible as acetic acid (International Cancer Control Partnership, 2019).

After an abnormal triage test such as cytology, HPV, or VIA, the need for evaluation by colposcopy with biopsy is the gold standard for evaluation of cervical dysplasia (World Health Organization, 2014). For both colposcopy and VIA evaluation, training is required for interpretation of abnormal findings by a HCW or specialist. An adjunctive method includes cervicography, the obtaining images of the cervix during these procedures, which can aid in the storage or dissemination of cervical pictures for consultation, review, quality improvement or educational programs. Methods used to obtain and use these images have varied through the years. In early years, images were produced on 35 mm slides and then projected onto screens for review. Digital cervicography (DC) is an emerging method in cervical cancer programs. Advancing technologies and mobile health (mHealth) allow for immediate digitization of images and have expanded the ability for interventions and program sustainability, maintenance, and evaluation beyond previously capable (WHO, 2019). For this paper, we refer to digital cervicography (DC) in this review specifically as the digital image collection of the cervix in cervical cancer screening programs.

To the best of our knowledge, there are no published systematic or scoping reviews evaluating the overall use of digital cervicography and its role with advancing screening programs in low-resource settings. In addition, the terminology, methods for how cervicography is performed, used, and disseminated vary in each program. As opposed to a systematic review which can provide statements to guide clinical decision-making, confirm and establish the quality of a practice, a scoping review can set the stage to identify key concepts, factors, and definitions in the literature. This scoping review best explores this diversity of evidence, particularly in LMICs or other low-resource settings which are using DC ad hoc to fill critical gaps to provide cervical cancer screening.

This scoping review seeks to synthesize published knowledge and evidence about the use of cervicography in improving cervical cancer screening programs in LMICs. We aim to understand how digital cervicography is used in LMICs, methods images are obtained, and their impact in cervical cancer screening programs.

2. Methods

2.1. Aims and objectives of the review

An initial systematic literature review on the impacts of cervicography on cervical cancer programs in low-resource settings was performed. The wide range of digital cervicography methods to obtain, use, and disseminate cervical images in screening programs suggest the use of a scoping review (Munn et al., 2018; Tricco et al., 2018). By synthesizing vast amounts of literature, the aim of this scoping review will provide insights into understanding the general or common characteristics of digital cervicography, use of cervical images, and how it is integrated into cervical cancer screening programs. The following research questions were investigated:

- What are the methods for digital cervicography in low- to middle-income countries?
- What are different ways digital cervicography is used in cervical cancer screening programs in LMICs?

Briefly, the search strategy included a set of keywords on cervix, cancer, and digital or mHealth identified with the help of a library specialist for electronic bibliographic search. An additional file shows the keywords in detail (Supplement A).

2.2. Identification of relevant studies

Original peer-reviewed articles published in the English language from January 1993 to October 2021 were obtained from two systematic searches of eight electronic bibliographic databases to include: PubMed, Scopus, Web of Science, CINAHL, Cochrane, Medicus, WHO IRIS and WHO PAHO in July 2020 with an identical search in May 2022. All identified articles from the searches were transferred to a reference manager software (EndNote, X8 Thomson Reuters) and all duplicates and titles in other languages were removed. The EndNote file was later transferred to an online systematic review software (Covidence, Cochrane, Melbourne VIC, Australia) for screening. The PICOS (participants, intervention, context, outcomes, and study design) framework was used to establish eligibility criteria.

To be included, original papers had to meet three criteria. First, the study was in a low-income or middle-income country (LMICs) as defined by the World Bank. Second, the study included interventions which were used in a program setting where participants were screened for cervical cancer thereby excluding any programs which used cervicography for interventions in treatment or post-treatment follow-up. Similarly, many abstracts and conference proceedings included research on the development of automatic detection programs, mobile colposcopes or other artificial intelligence were excluded as they were not used in a study involving participants for cervical cancer screening. Third, the study must use digital cervicography as an intervention method which is defined as not only taking images of the cervix (cervicography) but creating a digitized image which has potential for storage, transmission, and manipulation by a computer. Grey literature, narratives, commentaries, or other document types such as reports and essays were excluded.

2.3. Selection of relevant and reliable studies

By applying the eligibility criteria, two reviewers (TC and MS) have screened the articles for selection. The first selection was from title and abstract screening and the second one was from a full-text screening. All conflicts generated through the screening stages between the two reviewers were discussed until consensus was reached. A third reviewer (KK or CW) resolved any conflicts.

2.4. Data charting process and items

Once articles were selected two reviewers were randomized assigned to each article and determined which variables to abstract and independently charted the data. Reviewers discussed the results, and continuously updated the data-charting form in an iterative process, a third reviewer resolved any inconsistencies or disagreements. The data from eligible sources were abstracted using a standardized abstraction tool and abstracted data on study characteristics, participant information, level of intervention, type of intervention, methods and use of DC in the studies. Further descriptions of the categories are summarized here;

- *Participant Information* was abstracted making note of the number of participants enrolled in the study and undergone screening using DC, age of patients (range, median, mean), and if a special target population was included such as known human immunodeficiency virus (HIV) positive or exclusively pregnant women.
- *Level of Screening* was differentiated between DC as an intervention either "initial first time" or "after triage method." Initial first time refers to the use of DC during initial screening for cervical cancer. After triage method is selected if patients had undergone prior screening with HPV testing, cytology testing, VIA, or other types of triage methods prior to evaluation for by DC.

- *Type of Device* was abstracted based on the category of device used (smartphone, digital camera, commercial product, etc.) and specific name of the device.
- *Use of DC* was abstracted if the study particularly mentioned the use of DC for transmitting images, storing images, task-shifting, or use of remote review for cervical images. Task-shifting is the process of delegating level-appropriate tasks to less specialized healthcare workers (HCW) thereby increasing health care coverage and utilizing already available human resources. Utilization of a remote reviewer's location and timeliness of feedback was also extracted.

3. Results

3.1. Identification of potential studies

The searches from the eight electronic databases retrieved a total of 2143 records (PubMed: 671, Scopus: 670; Web of Science: 504; CINAHL: 109; Cochrane: 95; Medicus: 28; WHO IRIS: 55; WHO PAHO: 12). Ten additional records were retrieved from review of references from other studies. A total of 1244 titles and abstracts were screened after the removal of duplicates. We retrieved a total of 368 full-text articles for full-text screening review which led to 65 potentially relevant articles to our scoping review. Additional articles were excluded for reasons mentioned in the flowchart (Fig. 1). A total of 53 articles were included in our final data extraction and narrative account stages.

3.2. Characteristics of included studies

Summary of study characteristics (Table 1) included in this scoping review (n = 53) consisted of studies from 22 countries published between 1993 and 2021 were all cross-sectional studies. Map and list of unique countries can be found in Fig. 2 and Table 2.

Majority of studies analyzed clinical performance (n = 24), feasibility or acceptability (n = 19), review of the program method(s) (n = 9) and one cohort analyzed risk factors in HIV patients. Number of study participants ranged widely from 21 to 56,427 with age range between 14 and 80 years although many studies followed the WHO recommendation for screening between 30 and 65 years of age. Inclusion and exclusion criteria for studies were consistent for standard practice for cervical cancer screening with many countries recruiting participants who were presenting for first-in-lifetime screening for cervical cancer. Of the studies, seven studies included exclusively women living with HIV and two studies were on pregnant women.

3.3. Terminology

Differences in terminology used showed majority of studies (n = 46) referred visual inspection with acetic acid as VIA although some studies used direct visual inspection (DVI) (n = 3), acetic acid test (AAT) (n = 3), or naked eye visual screening (NE tests) (n = 1). The terms used for obtaining cervical images and storage into a digital format were also variable. Overall the majority of studies (n = 41) used similar terms such as digital-VIA, modified cervicography, VIA with cervicography (VIA-C) or VIA with digital cervicography (VIA-DC). The other unique terms for DC were cervical digital photography (CDP), digital assessment of the reproductive tract (DART), smartphone enhanced VIA (SEVIA), digital cervical screening test, smart phone colposcopy, digital colposcopy, or photographic inspection with acetic acid (PIA). In addition, there were four studies which used the term digital colposcopy when referring to the novel device and application program, Enhanced Visual

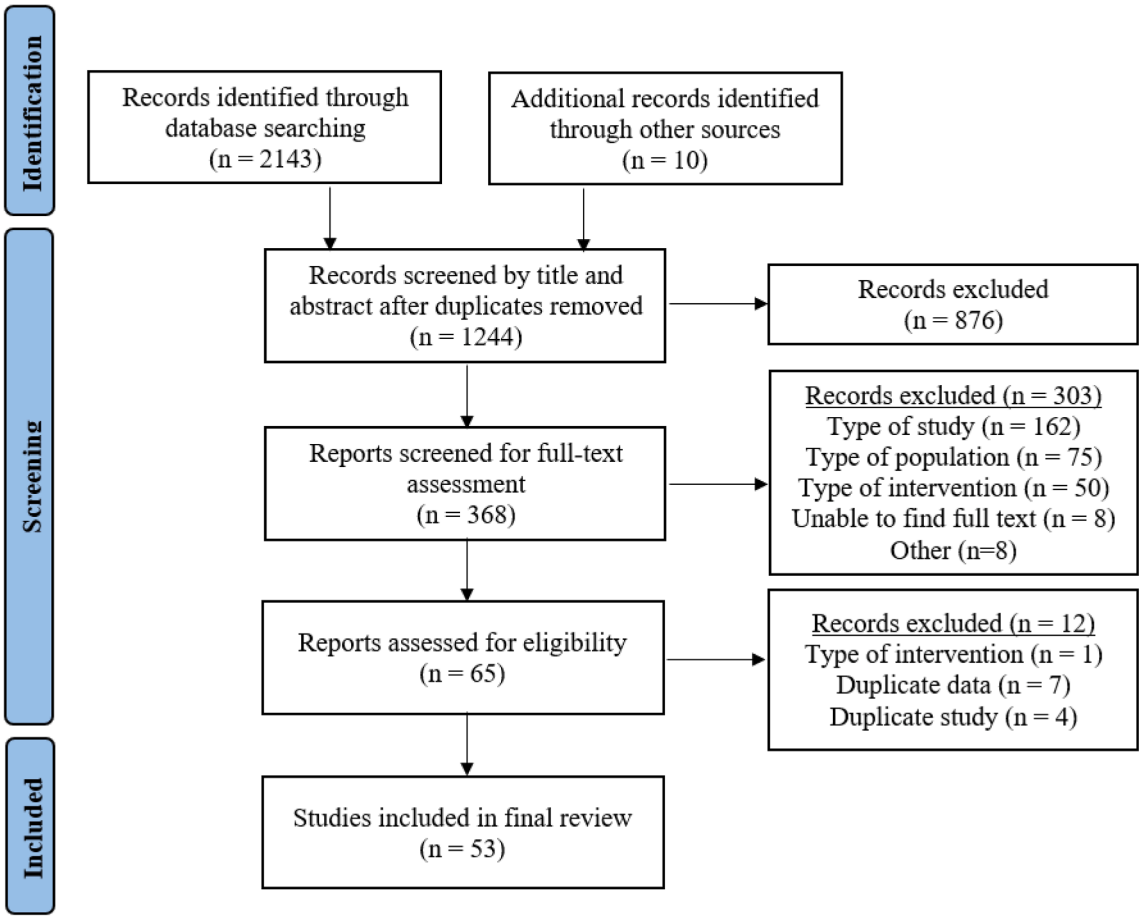

Fig. 1. PRISMA flow diagram of selection of articles.

Table 1
Summary of study characteristics grouped by type of device used in screening program.

	Study	Country	Objective	N	Age range	Age mean (median)	Sensitivity of DC (CIN2 +)	Specificity of DC (CIN2 +)	Terminology	Name of Device
Digital Camera	Bateman et al. (2014)	Zambia	Clinical performance of DC vs other methods	303*	20–45		0.84‡	0.58‡	Digital Cervicography	n/a
	Bomfim-Hyppólito et al. (2006)	Brazil	Clinical performance of DC vs other methods	1292	18–70	27.6	1.00†	0.69†	Digital Cervicography	Sony® Mavica FD-71
	Chibwesha et al. (2016)	Zambia	Clinical performance of DC vs other methods	200*	34–47		0.59‡	0.88‡	Digital Cervicography	Not specified
	Cremer et al. (2005)	El Salvador	Feasibility of DC as primary screening method	207	18–75		0.86‡	0.86‡	DART	Nikon® CoolPix
	Cremer et al. (2010)	El Salvador	Feasibility of DC as primary screening method	207	18–70	42	0.98‡	0.24‡	DART	Nikon® Coopix 5400
	DeGregorio et al. (2016)	Cameroon	Prevalence and predictors or risk factors	46,048	18+	(38)			VIA-DC	n/a
	Fokom Domgue et al. (2020)	Cameroon	Feasibility of two-stage screening with self-collect HPV then DC	196	30–65	44.7			VIA-DC	Olympus® SP-510 Ultra Zoom
	Fallala and Mash (2015)	Zimbabwe	Feasibility of DC with follow up results	4,641		39			VIAC	n/a
	Firnhaber et al. (2015)	South Africa	Program review of training program and performance of DC	1,202*	18–65	37	0.65†	0.69†	Digital Cervicography	Canon® PowerShot A590
	Hillmann et al. (2013)	Brazil	Clinical performance of DC vs other methods	176		45.75	0.84	0.96	CDP	Sony® Cyber-shot DSC-W 120
	Khodakarami et al. (2011)	Iran	Clinical performance of DC vs other methods	100	20–60	36	0.47	0.98	Digital Cervicography	Sony® DSC-W35
	Manga et al. (2015)	Cameroon	Program review of interobserver agreement of DC	14,376					Digital Cervicography	Olympus® SP-510, Canon® SX50 HS
	Mwanahamuntu et al. (2013)	Zambia	Program review and identification of risk factors by HIV status	56,427	26–39	(32)			Digital Cervicography	n/a
	Parham et al. (2010)	Zambia	Program review and outcomes in HIV positive patients	6,572*	N/A	34.2			Digital Cervicography	n/a
	Purwoto et al. (2017)	Indonesia	Clinical performance of DC vs other methods	185	20–55		0.98	0.91	Modified cervicography	Sony® Type W220
	Rodrigues et al. (2013)	Brazil	Acceptability of DC as complement to pap smear	63	14–78	38.4			Digital Cervicography	n/a
	Sharma et al. (2018)	India	Feasibility of nurse-led screening program	180		38.79			Digital Cervicography	n/a
Smartphone Camera	Asgary et al. (2019)	Ghana	Explore acceptability and feasibility	21	25–45	33.8			Cervicography	Samsung® Duo
	Asgary et al. (2020)	Eswatini	Impact of DC on improving reliability, reproducibility, and quality of VIA	247		30.8			Cervicography	Samsung® Duo
	Aydın et al. (2021)	Turkey	Clinical performance of DC vs conventional colposcopy	114	21–61	39.5	0.88†	0.49†	Smart Phone Colposcopy	iphone® 8 plus
	Catarino et al. (2015)	Madagascar	Feasibility of remote review	332	30–65	44.7	0.67†	0.86†	D-VIA	Samsung® Galaxy S5
	Cholli et al. (2018)	Cameroon	Feasibility of paired testing methods	913	30–80	42			VIA-DC	n/a
	Gallay et al. (2017)	Madagascar	Acceptability of a smartphone application	56	30–65				Cervicography	Samsung® Galaxy S5
	Mungo et al. (2021)	Kenya	Feasibility and acceptability of DC among HIV positive patients	94*	24–49	37.3	0.26‡	0.92‡	Cervicography	Samsung® J8
	Quercia et al. (2018)	Madagascar	Feasibility of mHealth application	151	30–65	41.8			Digital Cervicography	Samsung® Galaxy S5
	Quinley et al. (2011)	Botswana	Program review of remote reviewer for DC	95*					PIA	Samsung® SGH-U900
	Ricard-Gauthier et al. (2015)	Madagascar	Clinical performance and feasibility of DC with smartphone	300		43			Digital Cervicography	Samsung® Galaxy S4
	Tran et al. (2018)	Madagascar	Clinical performance of DC with smartphone	125	30–69		0.71‡	0.62‡	D-VIA	Samsung® Galaxy S5
	Urner et al. (2017)	Madagascar		187	30–69	39.7	0.94‡	0.5‡	D-VIA; D-VILI	

(*continued on next page*)

Table 1 (*continued*)

	Study	Country	Objective	N	Age range	Age mean (median)	Sensitivity of DC (CIN2 +)	Specificity of DC (CIN2 +)	Terminology	Name of Device
			Clinical performance of DC with smartphone							Samsung® Galaxy S4 or S5
	Yeates et al. (2016)	Tanzania	Feasibility of smartphone-based DC in screening program	1,072	25–49				SEVIA	iPhone® 5S
	Yeates et al. (2020)	Tanzania	Program review and impact of DC in screening program	9,142	25–49				SEVIA	n/a
Other (Cerviscope®, EVA®, or other novel device)	Cronjé et al. (2000)	South Africa	Clinical performance of DC vs other methods	842**	15–40	27			Cervicography	Cerviscope®
	Cronjé et al. (2001)	South Africa	Clinical performance of DC vs other methods	6301		34.4			Cervicography	Cerviscope®
	Cronjé et al. (2003)	South Africa	Clinical performance of DC vs other methods	1,286	30+	38.6			Cervicography	Cerviscope®
	Denny et al. (2000) (1)	South Africa	Program review of VIA with DC	2,944	35–65	(39)	0.58	0.93	Cervicography	Cerviscope®
	Denny et al. (2000) (2)	South Africa	Clinical performance DC as two-stage screening with VIA	1,423	35–65	(39)	0.71	0.88	Cervicography	Cerviscope®
	Denny et al. (2002)	South Africa	Clinical performance DC as two-stage screening with VIA	2,754	36–65		0.58	0.50	Cervicography	Cerviscope®
	De Vuyst et al. (2005)	Kenya	Clinical performance of DC vs other methods	548*	N/A	35.8	0.72	0.91	Cervicography	Cerviscope®
	Gasperin et al. (2012)	Brazil	Clinical performance of DC vs other methods	1,176	18–45				Cervicography	Cerviscope®
	Kesic et al. (1993)	Serbia	Clinical performance of DC vs other methods	418	N/A		0.89	0.92	Cervicography	Cerviscope®
	Kuhn et al. (2000)	South Africa	Clinical performance of HPV vs other methods	2,944	35–65				Cervicography	Cerviscope®
	Longatto-Filho et al. (2012)	Brazil and Argentina	Clinical performance of DC vs other methods	12,114		37.9	0.29	0.97	Cervicography	Cerviscope®
	Schneider et al. (2002)	Costa Rica	Clinical performance of DC	414	N/A		0.64	0.94	Cervicography	Cerviscope®
	Goldstein et al. (2020) (1)	China	Feasibility of DC with HPV co-testing	168	35–65				Digital Colposcopy	EVA®
	Goldstein et al. (2020) (2)	China	Feasibility of DC with HPV co-testing	552	30–64	45.4			digital Colposcopy	EVA®
	Peterson et al. (2016)	Kenya	Program review and analysis of new device	824					Digital Colposcopy	EVA®
	Thay et al. (2019)	Cambodia	Feasibility of novel device for DC in screening program	250	30–49				Digital Cervicography	EVA®
	Gabaza et al. (2019)	Zimbabwe	Descriptive review of program to identify treatment gaps	46,217	19–50				VIAC	Not specified
	Gharabaghi et al. (2019)	Iran	Clinical performance of DC	95			0.89	0.82	Cervicography	Specialized Cervicography Camera
	Oyiengo et al. (2018)	India	Acceptability of DC for prenatal screening	331**	18–42	26.7			Cervicography	Not specified
	Rahatgaonkar et al. (2020)	India	Comparison of Smart Scope test vs VIA and cytology	509	25–65	38.9			Digital Cervical Screening Test	Smart Scope®
	Singhakum et al. (2018)	Thailand	Clinical performance of DC with novel device vs other method	325		46.56	0.72	0.97	Digital Cervicography	Customized USB Handheld Device
	Srinivas et al. (2021)	India	Feasibility of DC in screening program	176	27–59	39			Gynocular triage-to-diagnose	Gynocular™

*HIV Positive **Pregnant †Obtained from biopsies of abnormal finding(s) on cervix ‡Obtained from biopsies if abnormal finding(s) or at least one quadrant if no lesions identified. Abrev: Cross sectional (CS), retrospective cohort (retro cohort), cervical intraepithelial neoplasia (CIN), digital cervicography (DC), visual inspection with acetic acid (VIA), human papillomavirus (HPV), digital assessment of the reproductive tract (DART), cervical digital photography (CDP), photographic inspection with acetic acid (PIA), smartphone enhanced VIA (SEVIA), visual inspection with Lugol's Iodine (VILI), Enhanced Visual Assessment (EVA®).

Assessment® (EVA®) (MobileODT, Israel), and one study using Gynocular triage-to-diagnose when using the Gynocular™ device (Gynius, A.B. Stockholm, Sweden).

3.4. Devices

The type of device chosen and specific uses of the images in the study protocols varied widely (Table 1). There were three general types of devices used: digital camera, smartphone, or another custom device. Digital cameras were used in 17 studies published between 2004 and 2020 in nine unique countries and for a total of 75,645 study participants. The types of devices ranged widely between make (Sony®, Nikon®, Olympus®, Canon®, etc.) and models. Some studies simply mentioned that a commercially available digital camera was used.

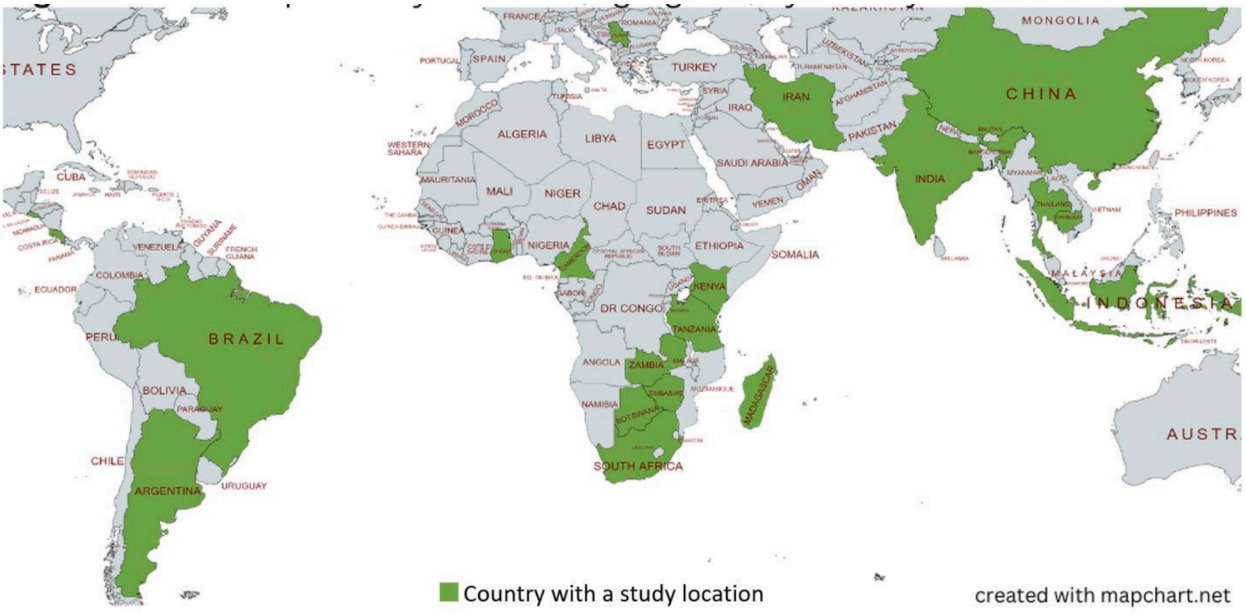

Fig. 2. Global map of study location (highlighted)by country.

Table 2
Number of studies done in each LMIC.

Country	No. of studies
Botswana	1
Brazil	4
Brazil and Argentina	1
Cambodia	1
Cameroon	4
China	2
Costa Rica	1
El Salvador	2
Eswatini	1
Ghana	1
India	4
Indonesia	1
Iran	2
Kenya	3
Madagascar	6
Serbia	1
South Africa	8
Tanzania	2
Thailand	1
Turkey	1
Zambia	4
Zimbabwe	2
Grand Total	53

Additional equipment for some studies required the use of a stand, laptop, television, or software to shrink photos to a transmittable size.

Smartphones were used in 14 studies published between 2011 and 2021 in eight unique countries and for a total of 12,660 study participants. The types of devices were majority Samsung® with two using an iPhone® smartphone. The device in most studies used a fixed stand for support and no additional equipment, although reliance on the internet and telephone data packages contributed to additional costs.

Aside from digital cameras or smartphones, four custom devices were used: Cerviscope® (National Testing Laboratories Worldwide, Fenton, MO, USA), EVA® device, Gynocular™ device, and Smart Scope ® (model CX1.0, Periwinkle Technologies Pvt. Ltd., Pune, India). They each varied in cost and technical capability. The Cerviscope® was used in 12 studies published between 1993 and 2012 in six different countries and provided up to 4× magnification. It is unique as one of the first devices to be used for capturing cervical images. Although images are initially stored as 35 mm film, which was typically mailed for remote review by experienced colposcopists, some studies digitized the film into an electronic format. Therefore, any screening studies using a Cerviscope® were included despite unclear mention if all 35 mm film was converted to digital format.

The EVA® device was another unique device which was a custom adaptation to a Samsung® Galaxy smartphone housed in a case that features additional magnification, stabilizer, optics, and attachable stand. Although this device uses a standard smartphone as an integrated component, it closely resembles a colposcope in capability and is referred to as digital colposcopy in two studies (Goldstein et al., 2020; Peterson et al., 2016; Thay et al., 2019; Gabaza et al., 2019; Gharabaghi et al., 2019; Oyiengo et al., 2018; Rahatgaonkar et al., 2020; Singhakum et al., 2018; Srinivas et al., 2021; Medical doctors, 2021; Asgary et al., 2016).

Four other studies did not include any of the above devices: in a 2018 study by Singhakum et al., the custom device was described as "portable customized handheld digital cervicography camera," but the article otherwise did not describe specifics (Srinivas et al., 2021). In a 2019 study by Garabaghi et al., investigators described their device as a "specialized cervicography camera," also did not include specifics (Rahatgaonkar et al., 2020). Two other studies did not specify their method to obtaining cervical imaging (Gharabaghi et al., 2019; Rahatgaonkar et al., 2020).

3.5. Clinical performance

There were 24 studies with main objectives to evaluate clinical performance of DC either by itself, as a co-testing method, or versus other screening tools such as VIA alone, HPV testing, conventional colposcopy, or cytology. Of all the studies included in this scoping review, 21 studies reported sensitivities and specificities of DC for detecting advanced dysplasia (CIN 2+) with a range of sensitivities (26–100 %) and specificities (24–98 %). Among studies which included only participants living with HIV, sensitivities ranged from 26 to 84 % and specificities ranged from 58 to 92 %. Methods in obtaining sensitivity and specificity data for DC varied across studies. Four studies obtained biopsies on participants who were found to have abnormal lesions during DC or VIA interpretation. Seven studies also obtained biopsies on any abnormal lesions as well as any cervixes that were interpreted as normal, commonly at the 6o'clock position. Overall, all

studies determined clinical performance of DC was sufficient in screening program in low-resource settings and could be used as either standalone screening test, in a two-step approach to screening, or as a co-testing method either with cytology or HPV for screening programs.

3.6. Feasibility and acceptability

There were 19 studies which evaluated the feasibility or acceptability of DC in screening programs with all studies concluding that DC regardless of the type of device was a feasible or accepted method. In a 2019 study by Asgary et al., the program used a smartphone for DC as a supplement for HCW training and included three months of mentorship by remote reviewers. They concluded improved training support and better communication with patients for targeted education improve adherence (Asgary et al., 2019). Similarly, in a 2018 study by Quercia et al., using a smartphone reported that DC helped HCWs with decision making and management options, including image sharing during the time of referral (Mungo et al., 2021). Using same-day screen-and-treat models was also demonstrated in many studies. For example, a 2015 study by Fallala et al., digital cervicography using a digital camera, immediately followed by cryotherapy or loop electrosurgical excision procedure (LEEP), if indicated, found this method was safe, acceptable, and feasible with positive outcomes (Fallala and Mash, 2015).

Overall, these studies did find technical problems such as power outages, logistical challenges, issues with data or internet connectivity reliability, and application limitations to be concerns with DC implementation in certain screening programs.

3.7. Program review

Studies that evaluated program methods as their main objective (n = 9) reviewed aspects such as clinical outcomes, program operations, utilization, identification of risk factors, interobserver agreement, use of remote review and descriptive review to identify gaps. In a 2015 program review by Firnhaber et al. using a digital camera, the training program for nurses had initial improvements in sensitivities from 65 % to 75 % for VIA when DC was added for specialist review and feedback, although over time, there was little significance in improved sensitivities (Firnhaber et al., 2015). They concluded that DC has benefit as an adjunct to VIA for training purposes with specialist support, especially due to low costs of the intervention ($2200 for the camera, television for projection of images, and laptop for storage). Similarly, in a 2013 study by Mwanahamuntu et al., using a digital camera, also concluded that DC provided improvement in VIA performance, and that it was a low-cost adaption and program quality assurance through telemedicine support (Mwanahamuntu et al., 2013). Two review studies focused on the analysis of interobserver agreement of DC with remote reviewers, finding strength in the agreements and acceptability in mobile telemedicine to increase access in same-day screen-and-treat programs (DeGregorio et al., 2016; Quercia et al., 2018).

3.8. Transmission and storage

Methods for transmitting images, if mentioned, were Google Forms, WhatsApp, MMS texting, email, or cloud-based server. While the specifics regarding security and patient confidentiality were addressed by some, the HIPAA-compliant capabilities of these technologies are unclear. All studies provided informed consent either written, verbal, and/or specific to the obtaining and transmission of cervical images. For studies that did specify the method of storage of digital images, those included the use of a central database, Google storage, other cloud-based storage, laptop with backup on institutional server, SD card, or secure email. To address concerns regarding capturing images on a smartphone and potential breech of patient confidentiality, studies such as ones by Asgary et al. (2020) and Ricard-Gauthier et al. (2015) removed sim cards from password protected phones and/or designated smartphones only for the purpose of the study. Some programs used a unique mobile application such as MobileODT® compatible with the EVA® device, SEVIA, or Triage-To-Diagnose application with the Gynocular™ device. For studies which transmitted images for remote review solely for the purpose of the study and not clinical decision making, images were commonly de-identified or anonymous.

3.9. Task sharing and remote review

Task sharing, using HCWs other than physicians or specialists, were specifically mentioned as a benefit for 27 studies. Task sharing commonly involved using less specialized HCWs, such as nurses or midwives, to perform the exam and obtain the cervical images. There were 30 studies that included the use of a remote reviewer, commonly for purpose of the study to obtain interrater reliability, quality assurance, or determine DC or VIA diagnostic accuracy, although ten studies were specifically mentioned the use of the feedback from the remote reviewer to guide treatment decision making. During the mentorship period in the 2019 study by Asgary et al., patients were informed of the need for confirmation of the diagnosis by the mentor (Asgary et al., 2019). Feedback turnaround time ranged, seven studies specifically noting immediate review or feedback within an hour and 18 studies reported feedback was delayed or did not specify turnaround time. In the 2016 study by Yeates et al., turnaround time was reported with 48.4 % of expert feedback returned to the on-site clinician within 1–5 min (Yeates et al., 2016).

Feedback was returned to the study team or the on-site clinicians through various methods with 13 studies specifically describing these methods. Many studies provided feedback as categorical: negative, atypical, or positive for acetowhite changes, concerning for cancer, or technically defective/inconclusive due to the quality of the image. Studies such as ones by Singhakum et al. (2018) and Srinivas et al. (2020) used a scoring system such as Reid's Colposcopic Index or Swede score, respectively, to describe any concerning lesions (Srinivas et al., 2021; Medical doctors, 2021). Feedback in studies by Gallay et al. (2017) and Mungo et al. (2021) included feedback on the quality of the image such as sharpness, focus, and zoom (Gallay et al., 2017; Mungo et al., 2021). Studies which used their own unique application or platform included features for reporting of feedback in a standard form such as the study by Yeates et al. (2020) which used their SEVIA provider portal to blind reviewers and if not in agreement with interpretation encouraged clinical mentorship with on-site clinician to guide next steps in client care (Khodakarami et al., 2011).

During the extraction process, attempts were made to differentiate the type of reviewer (physicians, specialists, colposcopists, etc.) or location of the reviewer (in-country or international). Although this was difficult as reviewers were a blend in level of expertise, role, and/or location, it was noted that the use of the reviewer provided mentorship and supported learning or quality improvement. It was unclear in many studies if the feedback or interpretation from the remote reviewer was then relayed to the patient or remained with the original HCW who captured the cervical image and/or interpreted the findings.

4. Discussion

Cervical cancer in LMICs remains disproportionately high in incidence, morbidity and mortality compared to other parts of the world. Solutions that promote sustainability, feasibility, and are relevant to the resources available are needed. This scoping paper explores the use of DC based on different methods and uses in screening programs. Results demonstrated a unique use of DC in screening programs due to the ability to provide mentorship and peer support from remote locations by more experienced reviewers. This support through virtual and dynamic training helps in diagnostic and clinical management decision-making and ensures quality control programs (Catarino et al., 2015). Based on WHO reports, over 40 % of WHO Member States have less than ten

medical doctors per 10,000 population with uneven distribution of health workers across the globe. This is below the recommendations for minimum density threshold of 22.8 skilled professionals per 10,000 people to provide the most basic health coverage (Asgary et al., 2016). This use of DC promotes task sharing and expands not only training capabilities but also continuous support with mHealth-supported VIA training over time to HCWs in countries with shortages to provide a possible solution (Asgary et al., 2016).

Methods for DC in LMICs varied in the types of devices used, terminology and how images are stored and transmitted. Consensus is needed in not only terminology but also in distinguishing what type of equipment is used to be qualified as DC, as this is particularly relevant due to differing quality, costs, and subsequent feasibility for programs in LMICs. Quality of images were addressed in studies which evaluated interrater reliability, although no standardization for recommended size or pixel minimum for quality standards were described. The technique in obtaining images was also a concern in some studies with need to define in study protocols specifics such as distance from introitus, angle, level of magnification, and light sources for reproducibility. Costs of devices can vary from hundreds to thousands of U.S. dollars and can be a significant barrier to screening implementation for many programs. In addition, technical assistance and user-friendliness are considerations which many feasible studies address as limitations to their screening programs.

The various methods of transmission and storage of images is another concern with the use of DC. Many studies lacked transparency on how images are stored and transmitted. Particularly, methods such as texting, WhatsApp, or Google Forms do not have known compliance standards, and programs using these methods would need to be evaluated for their patient confidentiality considerations. Costs of storage and transmission systems that do follow compliance standards may incur added expenses, thus creating additional barriers for low-resource settings. These methods need to be investigated further to recommend practice standards.

Overall acceptability in screening programs, particular in same day screen-and-treat approaches, found DC was feasible, decreased loss to follow-up, and could be scalable. In addition, using DC as an education tool for patients to promote awareness, understanding of cervical dysplasia, and need for treatment provided additional benefits.

Limitations to this scoping review were the lack of standardized terminology and distinction of what constituted digital cervicography. Only texts that were in the English language were included and eight full-text studies were not found. Additional studies using devices which are novel or custom developed may have also been missed due to designation as colposcopy-aided technology.

Further research is needed to validate the accuracy of DC as an adjunct to VIA or other screening techniques. While many studies accepted DC as a method for screening due to costs and feasibility, there are concerns that DC is not appropriate as a standalone test due to poor sensitivity or specificity. Subjective interpretation of the DC and reliance on continuous review and quality improvement for skills retention also need to be evaluated over time to make further recommendations of DC in screening programs.

5. Conclusion

Screening with VIA and ability to interpret for cervical dysplasia is an important skill, and many healthcare workers lack adequate training in LMICs. Regardless of newer and more accurate methods for cervical cancer screening such as HPV, cytology or other novel tests, the ability to perform a pelvic exam and provide a VIA interpretation for cervical dysplasia is a skill that will remain essential after any abnormal screening test. This scoping review provided an overview on the variety of ways DC can be employed in screening programs based on the program methods in terminology, device, storage, transmission, and uses of DC to provide mentorship, training, quality improvement and support for healthcare workers. The need for cheap and successful implementation in low-resource setting is essential for many LMICs with low screening participation and further support to scale up programs through feasible, cost-effective methods with additional research to validate the clinical performance of digital cervicography.

CRediT authorship contribution statement

Tana Chongsuwat: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Connor Wang:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Younji Sohn:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **Kathryn Klump:** Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Dr. Chongsuwat was supported by the University of Wisconsin Primary Care Research Fellowship, funded by grant T32HP10010 from the Health Resources and Services Administration.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gore.2022.101130.

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