RESEARCH ARTICLE

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Can portable Colposcopes Replace Standard-of-care Colposcopes? A Crossover Trial of Two Portable Colposcopes with a Standard-of-Care Video Colposcope

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Abstract

Background: Screen positive women need to be triaged by colposcopy which is a major challenge in low-middle income countries. Portable colposcopes may overcome many challenges, reduce referrals and enable a single visit approach. This study assessed the performance of portable colposcopes and potential to reduce referral. **Method:** This crossover randomised study enrolled women aged 25 to 65 years with abnormal screening result or cervical symptoms. All women underwent visual inspection with acetic acid (VIA), HPV test, colposcopy with two portable colposcopes (Gynocular®, Gynius, Sweden, and Pocket® transvaginal colposcope, Duke University, NC, USA) and a standard video colposcope, and biopsy. Colposcopic Swede score agreement between portable and video colposcopes, as well as agreement of Swede score with histology were calculated for each device. The potential impact of portable colposcopes in a single visit approach was assessed based on the final diagnosis. **Results:** Among 250 subjects, 27(10.80%) had high-grade cervical intraepithelial neoplasia (CIN2+) lesions. Swede scores for Pocket and Gynocular colposcopes were similar to video colposcope in 248 (99.20%) and 247 (98.80%) subjects, respectively (agreement scores 0.9969 and 0.9954, respectively). At a Swede score cut-off of ≥5, all three devices had identical sensitivity, specificity, positive and negative predictive value of 96.30%, 92.30%, 60.50% and 99.50,. Ablative treatment offered at field setting would result in optimal treatment in 52.0% and 85.1% cases when screened with VIA and HPV test respectively; using Pocket colposcope could improve this to 94.0% and 95.9%, respectively. Overtreatment and referral rates reduced from 46.8% and 12.4% to 4.8% and 6.0%, respectively, when VIA test is followed by triage with pocket colposcope. These outcomes were comparable to screening with HPV followed by colposcopy triage. **Conclusions:** Pocket colposcope performed comparably to the video colposcope. Used by healthcare providers in the field setting, they can augment the results of VIA significantly.

Keywords: Cervical cancer- screening- pocket transvaginal- portable colposcopes- low resource setting

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Introduction

Cervical cancer is the fourth most common cancer among women globally but the second most common cancer among women in India, with an estimated annual incidence and mortality of 123,907 and 77,348 cases, respectively, in 2020 (Sung et al., 2021). This is the scenario in most low and middle income countries (LMICs) with a low human development index. In developed countries, the establishment of national cytology-based screening programs with a call-and-recall system has successfully reduced the incidence of cervical cancer by 70% (Quinn et al., 1999). However, this model necessitates significant resources, including laboratories and skilled staff for specimen processing and evaluation, repeated rounds of screening, referral to colposcopy and multiple visits for diagnosis and treatment of screen positive women. Constraints in developing countries led to adoption of visual inspection with acetic acid (VIA) as the primary screening tool (Nahar, 2011; Poli et al., 2015; Sankaranarayanan et al., 2004). VIA positive women are referred to a higher centre for colposcopy

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and biopsy, however compliance is a problem. Moreover, the high false positive rate results in many women being referred needlessly. The recent call for elimination of cervical cancer by the World Health Organization (WHO) envisages HPV testing, which is presently not available or affordable in most LMICs. The advent of portable colposcopes in recent years offers an unprecedented opportunity to use affordable colposcopy to triage women at last mile facilities, with the use of tele-medicine or tele-mentoring.

The goal of the present study was to conduct a side-by-side comparison of performance of two such devices, the Gynocular® and Pocket® colposcope, to a standard video colposcope for detecting cervical intraepithelial neoplasia (CIN), thereby evaluating their potential to enable a single visit approach for screening and treatment by reducing referral rates as well as overtreatment. This is the first study comparing the performance of the transvaginal Pocket colposcope with other available options.

Materials and Methods

This crossover randomised study was carried out from September 2017 to June 2019 following approval from the Institutional Ethics Committee Sample size calculation was based on results of previous studies comparing the Gynocular with a standard colposcope (Ngonzi et al., 2013; Nessa et al., 2014). For a 3x3 table comparison with kappa statistics, a sample size of 250 subjects is required in order to detect statistically significant differences with 80% power and a 5% level of significance (1-sided), making allowances for up to 10% loss to follow-up.

Women referred to the Colposcopy Clinic were invited to participate in the study if they met the following inclusion criteria: age between 25 and 65 years, abnormal cervical screening result (Pap ≥ASCUS, VIA or HPV positive), vaginal discharge >6 months, postcoital bleeding, postmenopausal bleeding, or an unhealthy cervix on examination. Exclusion criteria included pregnancy, obvious cervical malignancy, previously diagnosed or treated cervical cancer or CIN, previous hysterectomy or procedures on the cervix, e.g., conization, trachelectomy, etc.

An informed written consent was obtained from all participants. Detailed history, including demographic and reproductive history, was obtained and a physical examination performed. Women then underwent colposcopy with the Gynocular® colposcope (Gynius AB, Stockholm, Sweden) the Pocket® colposcope (Duke University, NC, USA) and standard video colposcope (proMIS digital video colposcope COLpro222DX series, proMIS Medical, Australia).

The Gynocular is a relatively low-cost battery-operated portable colposcopic device. It weighs 420 g, measures 10 cm in length and provides 3x, 8x and 12x magnifications. It has an inbuilt green filter and LED light. It uses a smartphone and software for image, patient data storage and transmission (Ngonzi et al., 2013; Nessa et al., 2014). It can be mounted on a tripod stand or one with wheels.

The Pocket colposcope is a transvaginal colposcope developed at Duke University, NC, USA . It weighs 150 g and provides 5x-15x magnification. In addition, it has in-built illumination, auto-focus, and magnification capabilities, and anti-fog and waterproofing features (Mueller et al., 2017) It has a short focal length and can be inserted into the vaginal canal through a speculum and placed 3–4 cm away from the cervix. It has both white and green light emitting diodes (LEDs). An outer plastic sheath provided with the Pocket colposcope was used to cover the probe when inserted into the vaginal canal. It also uses a smartphone and software for image, patient data storage and transmission.

In this crossover trial, patients were electronically randomized to determine the sequence of use of the portable colposcopes (as shown in the consort diagram Figure 1). All colposcopic images were stored in an electronic database. Cervical lesions were assessed using the Swede score (Bowring et al., 2010). The cut-off for a colposcopic impression of high-grade CIN was a Swede score ≥5 (Ranga et al., 2017). Biopsy was guided by the findings of the video colposcope and obtained from all cervical lesions regardless of the Swede score. If no lesion was visualized, random four-quadrant biopsies were obtained from the squamocolumnar junction. VIA findings by field worker were documented for all patients.

The time taken for colposcopic examination with each device was recorded. The colposcopist completed a questionnaire regarding the operator experience and image quality for all three colposcopes, which included observations on various criteria, rated on a scale of 0 to 10, as well as open-ended questions regarding the advantages and disadvantages of each.

Standard disinfection procedures were followed. Disinfection of the Pocket colposcope was carried out in between cases in accordance with the instructions of use in the FDA submission. Excess body fluids were first removed with a fresh propanol-based germicidal wipe following which the standard disinfection procedure was followed (10 minute immersion in activated glutaraldehyde solution followed by rinsing in sterile saline water).

Cervical histopathological diagnosis was used as the reference standard. For those subjects who underwent a follow-up procedure, e.g., cone/loop biopsy or hysterectomy, the most severe diagnosis was used for data analysis. Agreement scores between the Pocket, Gynocular and video colposcopes were calculated using kappa statistics and a Spearman rank correlation coefficient. The average duration of time for the use of each device and the average scores for the operator experience were computed. Statistical analysis was performed with STATA 15.1 software (Stata Corp., USA).

The potential impact of the Pocket colposcope in the field setting was assessed by (i) the number of women who would fulfil the WHO criteria for ablative therapy and the number who would be referred to colposcopy based on VIA and HPV results alone; (ii) the number who would be treated/referred when colposcopy was added on; and (iii) calculating the optimal treatment rates and referral rates based on the histology results.

Results

A total of 250 women participated in the study. The sociodemographic characteristics are shown in Table 1. Mean age of the subjects was 41.0±9.30 years (range 25-65 years). The majority had completed schooling up to primary or middle school level (n=103, 41.20%). Approximately one-third of the subjects (n=75, 30%) belonged to lower to middle socioeconomic class (Oberoi SS, 2015). The majority were housewives (n=218, 87.20%) and married (n=238, 95.20%). Mean age at marriage was 17.80±3.20 years and at first pregnancy was 20.10±1.80 years. Majority (51.60%) of the study population had two children (range, 0-7); 89 (35.60%) women had used some form of contraception. Inclusion criteria were as follows: abnormal screening tests (n=120, 48%), persistent vaginal discharge (n=96, 38.40%), postcoital bleeding (n=24, 9.60%), postmenopausal bleeding (n=14, 5.60%), and unhealthy cervix (n=63, 25.20%). In 43 (17.20%) women, there was more than one inclusion criterion. The transformation zone (TZ) was completely visualised in 205 (82.0%) women: Type 1, n=173; Type 2, n=32). Type 3 TZ was found in 45 women; one them had an endocervical carcinoma that was not detected with any of the three devices. She had postmenopausal bleeding and was detected to have cervical cancer on fractional curettage. Imaging showed 2x1cm cervical mass near internal os with extension to lower uterine segment.

Table 1. Demograhic Characteristics of Subjects

Demograhic characterisitcs	Number (N=250)	Percentage (%)
Age in years		
<30	32	12.8
30-34	56	22.4
35-39	54	21.6
40-44	39	15.6
45-49	20	8.0
50-54	21	8.4
55-59	11	4.4
> 60	18	7.2
Occupation		
Housewife	218	87.2
unskilled	8	3.2
semiskilled	8	3.2
skilled	9	3.6
clerical	6	2.4
professional	1	0.4
Age at coitarche (in years)		
<16	4	1.6
16-20	162	64.8
21-25	75	30.0
>25	9	3.6
Age at first pregnancy (in years)		
<16	1	0.4
16-20	131	52.4
21-25	99	39.6
26-30	12	4.8
>31	2	0.8
Parity		
Nulliparous	5	2.0
one	13	5.2
two	129	51.6
>three	103	41.2
Menopausal status		
premenopausal	197	78.8
postmenopausal	53	21.2
Habit of consuming tobacco product	4	1.6

Swede scores were calculated for all three colposcopes. The scores for the Pocket and video colposcopes were identical in 248/250 (99.20%) women; in two (0.8%) patients there was a difference in the assessment of vessel patterns. Assessment of all other parameters showed perfect correlation. The mean Swede score was 2.52±2.47 (95% CI: 2.22-2.84) for the Pocket colposcope and 2.54±2.48 (95% CI: 2.22-2.85) for the video colposcope. There was high agreement between the two values of 99.92% (k-value 0.9969).

When calculated for the Gynocular and video colposcope, the Swede scores were the same in 247/250 (98.80%) women; in 3 (1.20%) patients, differences were found in assessment as follows: lesion margin (n=1); vessel pattern (n=2). Assessment of lesion size, aceto-whitening and iodine staining showed perfect correlation. The mean Swede score was 2.53±2.46 (95% CI: 2.21-2.84) for the Gynocular and 2.54±2.48 (95% CI: 2.22-2.85) for the video colposcope,. The weighted k-statistics showed almost perfect agreement between the two values (k- value 0.9954). The Swede score calculated with the portable colposcopes in comparison with the standard colposcope is shown in Table 2.

Final histopathological results were as follows: normal/ chronic cervicitis (n=195), condyloma acuminatum (n=1), tuberculosis (n=1), CIN1 (n=28), CIN2 (n=4), CIN3 (n=20), invasive cervical cancer (n=3). In cases with CIN2+, both the portable colposcopes had an agreement score of 85.56% with cervical histology and weighted k-value of 0.5015, showing moderate agreement. The video colposcope had an agreement score of 85.56% for CIN2+ with weighted k-value of 0.5055 showing moderate agreement.

The receiver operating characteristics curve (ROC curve) areas with Pocket, Gynocular and video colposcopes were similar (0.9620, 0.9620, 0.9130 respectively) showing high agreement in outcome measures calculated from the devices (Figures 2a-c). The comparison of colposcopic impression with cervical histology is shown in Table 3. At a Swede score cut-off of >5, all three devices had sensitivity, specificity, positive predictive value and negative predictive value of 96.30% (95%CI:81-99.90), 92.30% (95%CI:88-95.50), 60.50% (95%CI:44.40-75) and 99.50% (95%CI:97.30-100), respectively to detect CIN2+. Swede score at a cut-off of ≥5 had the highest sensitivity to detect CIN2+ lesions and Swede score ≥8 had the highest specificity and positive likelihood ratio to detect CIN2+ lesions. VIA had sensitivity, specificity,

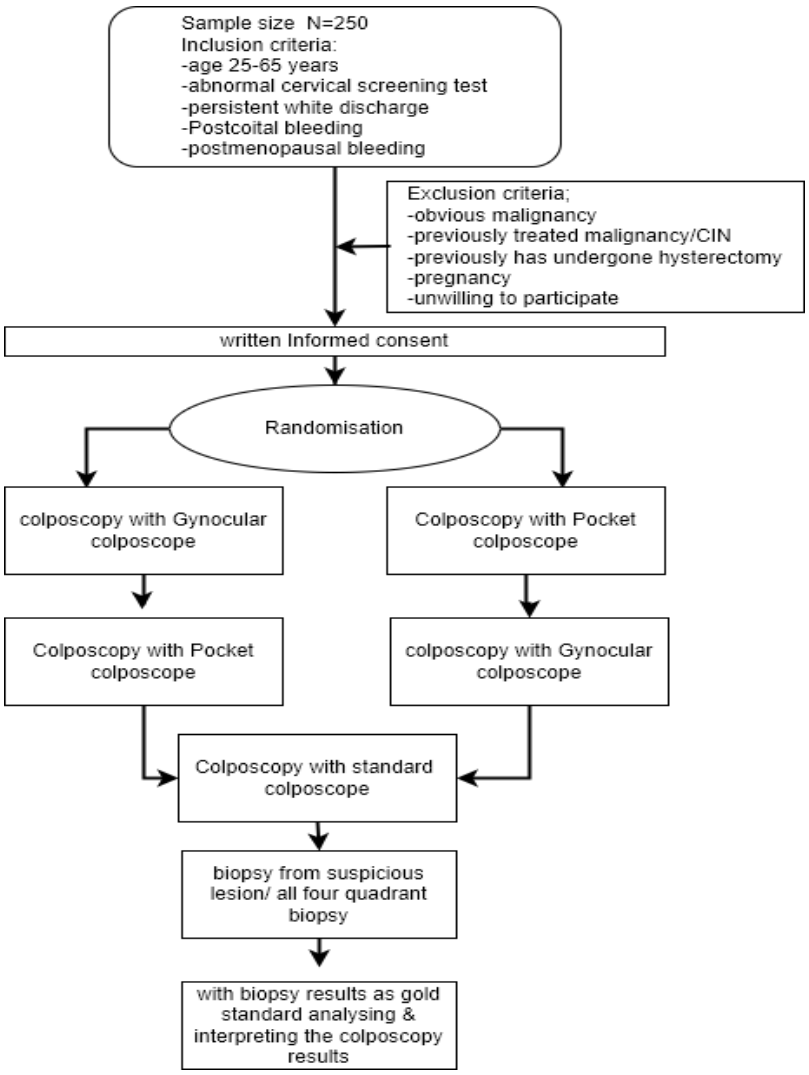

Figure 1. Consort Diagram of the Study

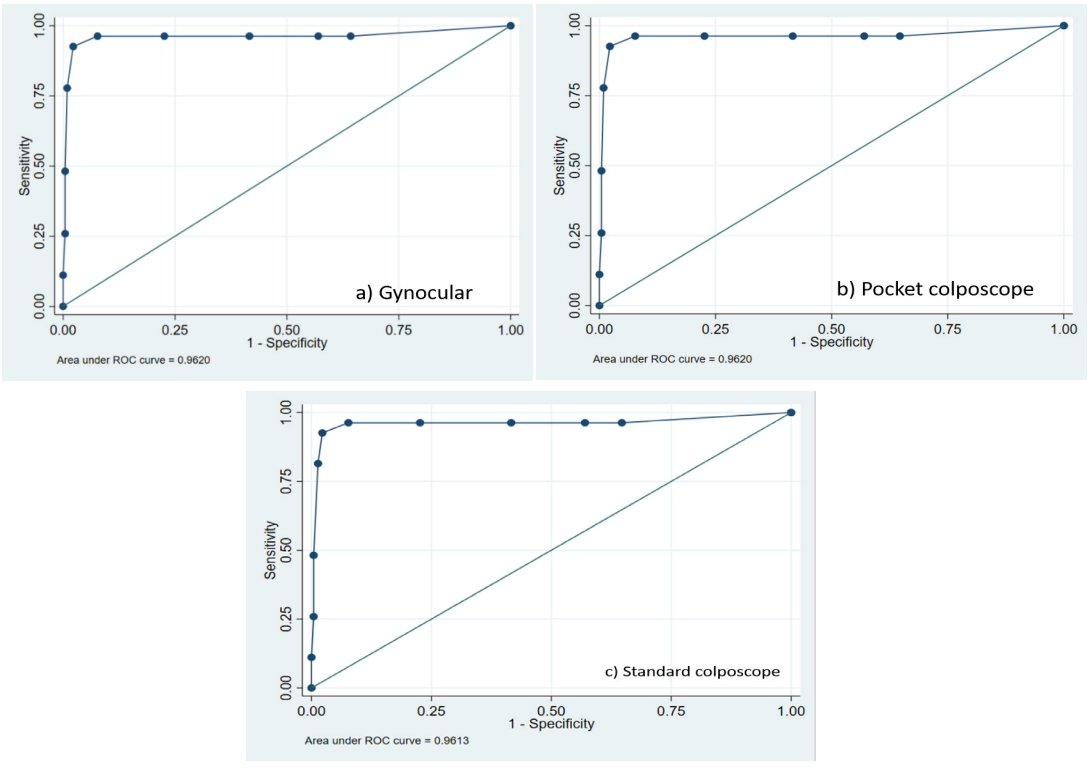

Figure 2. Receiver Operating Characteristics Curve for a) Pocket Colposcope, b) Gynocular ,c) Standard Colposcope

Table 2. Comparison of Swede Score with Pocket Colposcope, Gynocular Colposcope and Standard Colposcope

Comparison of Swede score with Pocket colposcope and Standard colposcope													
		Standard colposcope											
Pocket colposcope	Swede score	0	1	2	3	4	5	6	7	8	9	10	Total
	0	80	0	0	0	0	0	0	0	0	0	0	80
	1	0	17	0	0	0	0	0	0	0	0	0	17
	2	0	0	34	0	0	0	0	0	0	0	0	34
	3	0	0	0	42	0	0	0	0	0	0	0	42
	4	0	0	0	0	33	0	0	0	0	0	0	33
	5	0	0	0	0	0	13	0	0	0	0	0	13
	6	0	0	0	0	0	0	5	2	0	0	0	7
	7	0	0	0	0	0	0	0	9	0	0	0	9
	8	0	0	0	0	0	0	0	0	6	0	0	6
	9	0	0	0	0	0	0	0	0	0	3	0	3
	10	0	0	0	0	0	0	0	0	0	0	3	3
	Total	80	17	34	42	33	13	5	11	6	3	3	250
Comparison of Swede score with Gynocular colposcope and Standard colposcope													
Gynocular colposcope		Standard colposcope											
	Swede score	0	1	2	3	4	5	6	7	8	9	10	Total
	0	80	0	0	0	0	0	0	0	0	0	0	80
	1	0	17	0	0	0	0	0	0	0	0	0	17
	2	0	0	34	0	0	0	0	0	0	0	0	34
	3	0	0	0	42	0	0	0	0	0	0	0	42
	4	0	0	0	0	33	0	0	0	0	0	0	33
	5	0	0	0	0	0	12	1	0	0	0	0	13
	6	0	0	0	0	0	0	5	2	0	0	0	7
	7	0	0	0	0	0	0	0	9	0	0	0	9
	8	0	0	0	0	0	0	0	0	6	0	0	6
	9	0	0	0	0	0	0	0	0	0	3	0	3
	10	0	0	0	0	0	0	0	0	0	0	3	3
	Total	80	17	34	42	33	12	6	11	6	3	3	250

positive predictive value and negative predictive value of 96.30% (95%CI:81-99.90), 92.30% (95%CI:88-95.50), 60.50% (95%CI:44.40-75) and 99.50% (95%CI:97.30-100), respectively to detect CIN2+ when performed by field worker. Among 250 women screened, 66 were HPV positive, 176 were HPV negative, and 8 were HPV status unknown.

Figure 3 shows a set of cervical images captured by portable colposcopes. Table 4 shows the optical characteristics of the portable devices compared with video colposcope features. The Pocket colposcope scored better with respect to field of view, ease of use (the device needs less adjustment and handling when there is a change in patient position or in between procedures), ease of taking biopsy and subject compliance, although these differences were not statistically significant. The time needed for colposcopy with the Pocket colposcope, the Gynocular and the video colposcope were 259.30, 298.50, 308.90 seconds, respectively. All optical characteristics when analysed with Bartlett's test for equal variance showed significant homogenicity of variances with $P < 0.001$ showing that the performance of the Pocket colposcope was comparable to the standard videocolposcope.

The potential use of Pocket colposcope in screening setting with facility to provide ablative therapy was calculated by assessing the optimal treatment rate, overtreatment rate, undertreatment rate and referral rate. The optimal treatment rates were 52%, 92.4%, 86.4%, 95.9%, overtreatment rates were 46.8%, 4.8%, 13.6%, 0.8%, undertreatment rates were 1.2%, 1.2%, 1.2%, 1.6% and referral rates were 12.4%, 6.0%, 6.6%, 3.7% respectively for women undergoing VIA alone, VIA followed by colposcopy, HPV test alone, HPV test followed by colposcopy respectively.

Discussion

Cervical cancer continues to be a major public health problem in low- and middle-income countries (LMICs) which could never implement the systematic cytology-based screening programs of developed countries (Quinn et al., 1999). VIA emerged as a promising alternative screening tool, but the high false positive rate means several women will be referred unnecessarily to secondary

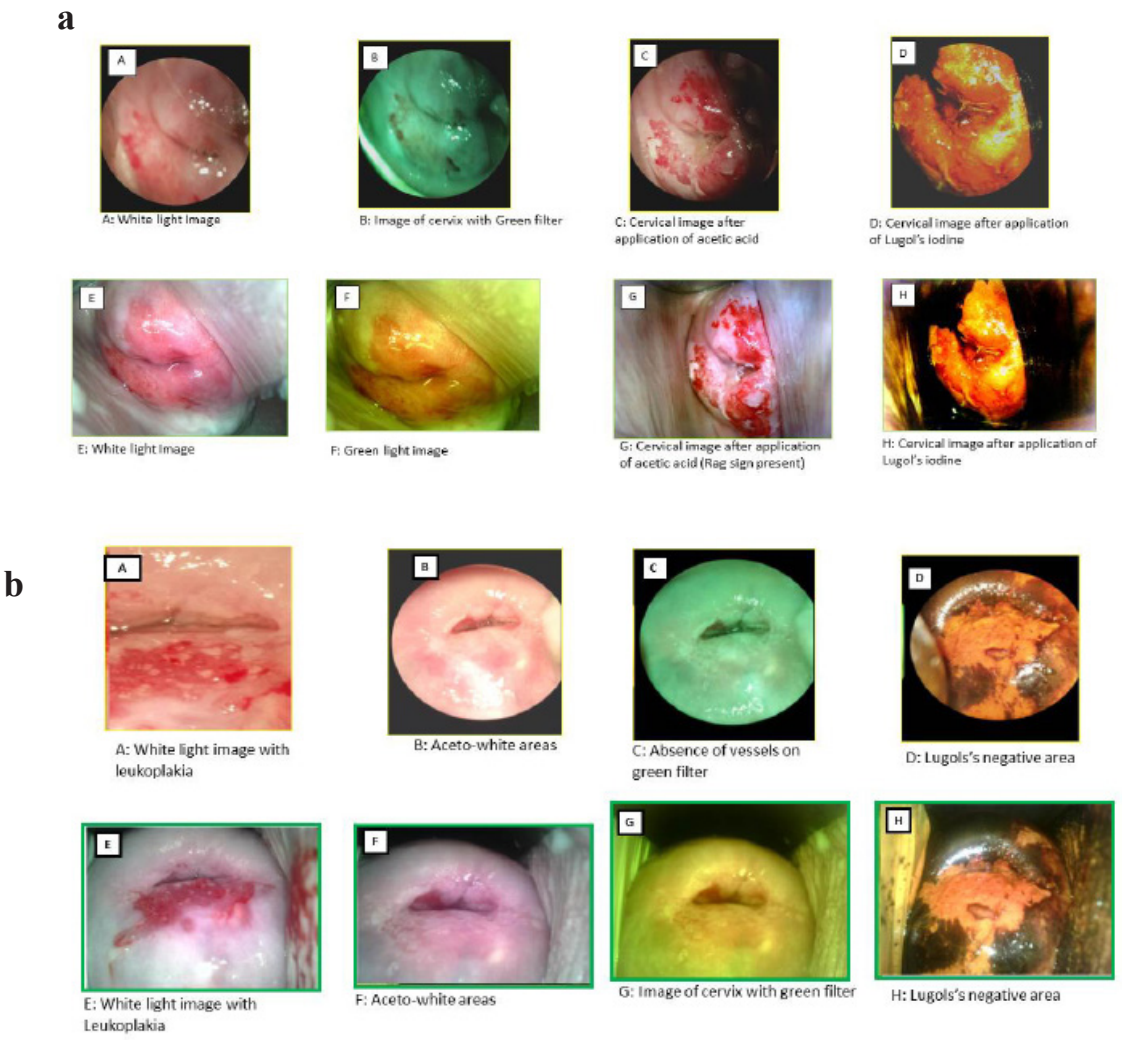

Figure 3. a; Images of Cervix in a Postmenopausal Woman with Persistent Discharge; Swede score 9; Histopathology CIN3. Narrowing of upper vagina was present. Images captured with Pocket colposcope scopes are better with broad field of vision due to focusing in close proximity to cervix). Images with Gynocular labelled A-D and images with pocket colposcope labelled. b; Images of cervix captured with Gynocular (A-D) and Pocket (E-H) colposcopes in a case with Type 2 Transformation Zone; Swede score 9; histopathology CIN3. Patient underwent conisation.

level facilities for colposcopy and triage. Low compliance with follow-up colposcopy reduces the effectiveness of current screening and diagnostic programs in countries such as India. This was seen in the first screening program started in the state of Tamil Nadu, India (TNHSP report). Several lessons were learnt from this program, including the significant dropout rate in a multi-step process, resulting in failure to treat a large proportion of screen-positive patients.

In 2018, WHO announced a call for the elimination of cervical cancer by 2030. It recommends that countries should aim for 70% of women to be screened at ages 35 and 45 years using a high-precision test, namely an HPV test, and 90% of cervical lesions should be treated. While the HPV test has high sensitivity, it has comparatively low specificity (Basu et al., 2015; Goldhaber-Fiebert et al., 2008). Thus women still need to be referred to secondary facilities that perform colposcopy and biopsy, as for VIA, and the majority will not have significant disease. This model requires significant linkages and cost is therefore not sustainable. Portable colposcopes can play an important role in minimizing referral of screen-positive

Table 3. Comparison od Swede Score on Colposcopy and Cervical Histopathology with All Three Devices

Swede score by colposcopy	Histopathology				
	Normal	CIN1	CIN2	CIN3/Ca	Total
0 to 4	182	22	0	1	205
5 to 6	9	6	1	4	20
7 to 10	2	0	3	18	23
Total	191	28	4	23	248

Table 4. Comparison of Optical Characteristics of Portable and Standard Colposcope

Optical characteristics	Score		
	Pocket colposcope Mean (standard deviation)	Gynocular Mean (standard deviation)	standard colposcope Mean (standard deviation)
Field of vision	9.16 (0.39)	8.24 (0.49)	8.30 0.52)
Depth of vision	8.04 (0.77)	7.93 (0.54)	8.81 (0.39)
Magnification	8.10 (0.87)	7.67 (0.52)	8.90 (0.25)
Ease of use	8.80 (0.59)	7.94 (0.41)	8.17 (0.39)
Ease of taking biopsy	7.85 (0.56)	7.36 (0.56)	7.04 (0.19)
Subject compliance	8.48 (0.63)	7.96 (0.44)	7.89 (0.34)
Time taken for Procedure (in seconds)	259.28 (34.39)	308.88 (30.96)	298.52 (24.51)
Adequacy of image for interpretation at the time of initial coloscopic evaluation	100%	100%	100%

women to secondary facilities especially the devices like Pocket colposcope which has incorporated features and design facilitating the usage by field workers.

In the present study, the median age at diagnosis of CIN2, CIN3, and invasive cancer was 35, 41, and 51 years, respectively. Only 1 of 4 women with CIN2 was aged 30 years, and 2 of 20 women with CIN3 were less than 35 years of age. This age distribution confirms the validity of the twice in a lifetime screening at 35 and 45 years being recommended by WHO, which would have picked up the majority (24/27, 88.90%) of women with CIN2+ lesions.

In the present study cervical histology was the reference standard. The agreement of Swede score by Pocket and Gynocular colposcope with cut-off of ≥5 to detect CIN2+, showed k-statistics 0.9969 and 0.9954, respectively, when compared to a standard colposcope ($P < 0.001$). There was some variation in the colposcopic impression in terms of Swede score obtained in 2/250 (0.80%) subjects with the Pocket, colposcope and in 3/250 (1.20%) subjects with the Gynocular when compared with the standard colposcope. However since this did not decrease the total score below the cut-off of 5, it did not change the colposcopic impression regarding severity of the lesion, nor did it impact management. The correlation with the standard colposcope was thus 100%. In a pilot study, Ngonzi et al. compared colposcopy results obtained with the Gynocular and a standard colposcope in 69 VIA positive women in a low resource setting (Ngonzi et al., 2013). The level of agreement in assessing cervical lesions was 70.10%, kappa statistics 0.6500 ($P < 0.001$). In another study, 6883 women in India aged >30 years underwent screening with VIA, HPV test, cervical cytology and the Gynocular at the same visit. VIA was positive in 344 (5%) women; HPV test was positive in 303 (4.40%). The sensitivity of Gynocular to detect CIN2+ at a threshold of IFCPC (International Federation of Cervical Pathology and Colposcopy) grade 1 and grade 2 abnormalities was 96.40%; and 92.90%, respectively. The specificity of Gynocular for grade 1 and 2 thresholds was 47.10 and 94.10%, respectively. The NPV was 99.70% at both thresholds (Basu et al., 2016). These results were comparable to the results seen in our study.

In vitro and pilot *in vivo* studies comparing cervical image concordance of Pocket colposcope with the standard colposcope with respect to image quality have shown that the Pocket colposcope has comparable resolving power, minimal lens distortion, accuracy, colour reproduction and illumination when compared to stationary colposcopes with substantially higher image contrast when compared to the standard colposcope (lam et al., 2015). In the two cohorts of 24 and 32 women, there was high agreement with the standard colposcope in 75% of the cases, with k-statistics 0.4000, P= .0028 and k-statistics, 0.4941, P= .0024, respectively (Lam et al.,2018). Although the Pocket has an anti-fogging capability, during the present study fogging of images was observed in 4 patients during the winter months when the ambient temperature was low. It was circumvented by immersing the probe in lukewarm water before examination.

In a study conducted in Peru, Mueller et al., (2018) compared the Pocket colposcope with a standard clinical colposcope. The agreement in interpretation of images from the two colposcopes was 83.10%. When compared to cervical histology, the sensitivity and specificity of colposcopy for detection of CIN2+ lesions using the Pocket colposcope was 80.70% and 57.50%, respectively, which was similar to the standard colposcope (82.20% and 56.60%, respectively.

When the VIA results by field worker was compared with the portable colposcopes the results of portable colposcope s not only improved the screening results but also reduced the time for examination since VIA needs a light source separately and the portable colposcopes have a inbuilt light source. The results were reproducible and were available for second look since the images were stored.

Portable colposcopes which operate outside the vaginal canal have similar requirements to standard colposcopes, namely, a working distance of 30-45 cm in order to view the cervix through a speculum. This increases the time and effort to focus the cervix and requires a stand to stabilize the viewing system. The Pocket colposcope provides a solution to these issues. This transvaginal device provides high quality images using low cost and ubiquitous LEDs and a camera at the tip of the colposcope. This obviates the need for high resolution cameras, powerful light sources and expensive optics. Moreover, not requiring a stand is an additional benefit. When Gynocular was used we found

the tripod stand to be somewhat unsteady, while the one on wheels tended to move unintentionally as it does not have a break, thus requiring refocussing.

The Pocket colposcope is expected to reduce the expertise needed by the operator to image the cervix making it more suitable for use in the community health setting. It can provide both white light and green images like standard colposcopes. The images captured can be displayed on a smartphone, tablet or laptop. Alternatively, they can be stored and transmitted to a remote site, thus making the interface between primary and secondary facilities more seamless. Triage in secondary level facilities is thus transitioned to the primary health care level, which, with the assistance of tele-medicine, could both increase efficiency and decrease loss to follow up. This does not completely remove the need for referral, but allows the majority of women without a visible lesion do not require referral for a colposcopy visit.

With our present study results it was found that the use of Pocket colposcope reduced the overtreatment rates with VIA-based screening considerably from 46.8% to 4.8% and referral rates reduced from 12.4% to 6%. This will improve the screening program outcomes by reducing the dropout rates. Optimal treatment rates with VIA based screening also increased from 52% to 94% leaving only 3 (1.2%) of screened women undertreated. Triage with pocket colposcope at field setting improved VIA based screening outcomes and the results were comparable to HPV test-based screening. In resource limited settings were HPV test-based screening is not feasible VIA-based screening with colposcopy triage with portable colposcope will bring desired outcomes. The cost of introducing colposcopy triage with pocket colposcope also will be significantly less and more feasible when compared to HPV test-based screening.

Ultimately, with tele-mentoring, there is potential for less trained health professionals to both detect and biopsy lesions for assessment at the health facility. Finally, the Pocket colposcope with a weight of less than 0.3 lbs. is expected to be significantly more portable (can be put in a coat pocket) and low-cost compared to the Gynocular, and other portable devices (Lam et al., 2015).

A limitation of this study is that it was conducted in the colposcopy clinic and results were extrapolated for field setting.

In conclusion, portable colposcopes have the potential to bridge the gaps in screening and triage by making it more cost-effective, user-friendly and accessible in LMICs where resources do not support a multi-step program or the transition to HPV testing. In the short term, these technologies could reduce the number of, false-positives that can be identified at last mile facilities and, in the longer term, combine triage and treatment in a single visit approach. This can transform the paradigm of screening and triage in LMICs.

Author Contribution Statement

The authors confirm contribution to the paper as follows: study conception and design: NB, JN, SVB, SK. Author; data collection: JN, SV; analysis and interpretation of results: NB, JN, SVB; draft manuscript preparation: JN, NR, SM, PT, JM, SS. All authors reviewed the results and approved the final version of the manuscript.

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Ethical clearance

Study was part of an approved thesis of first author. Study was approved by institutional review board of All India Institute of Medical Sciences, New Delhi.

Availability of data

The datasets generated during and/or analyzed during the current study are not publicly available due to confidentiality but are available from the corresponding author on reasonable request.

Study registration

The study was registered under clinical trial registry of India .

Conflicts of interest

None to declare.

References

Basu P, Mittal S, Banerjee D, et al (2015). Diagnostic accuracy of VIA and HPV detection as primary and sequential screening tests in a cervical cancer screening demonstration project in India. *Int J Cancer*, **137**, 859–67.

Basu P, Banerjee D, Mittal S, et al (2016). Evaluation of a compact, rechargeable, magnifying device to triage VIA and HPV positive women in a cervical cancer screening program in rural India. *Cancer CausesControl*, **27**, 1253–9.

Bowring J, Strander B, Young M, et al (2010). The Swede Score: Evaluation of a Scoring System Designed to Improve the Predictive Value of Colposcopy. *J Low Genit Tract Dis*, **14**, 301–5.

Goldhaber-Fiebert JD, Stout NK, Salomon JA, et al. (2008). Cost-effectiveness of cervical cancer screening with human papillomavirus DNA testing and HPV-16,18 vaccination. *J Natl Cancer Inst*, **100**, 308–20.

HDI | Human Development Reports [Internet]. Available from: http://hdr.undp.org/en/content/human-development-index-hdi [Accessed on 28 Nov 2020].

Sung H, Jacques F, Seigel R, et al. (2021) Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA J Clin*, **0**, 41. (Online)

Lam CT, Krieger MS, Gallagher JE, et al (2015). Design of a novel low cost point of care Tampon (POCkeT) colposcope for use in resource limited settings. *PLoS One*, **10**, e0135869.

Lam CT, Mueller J, Asma B, et al (2018) An integrated strategy for improving contrast, durability, and portability of a Pocket colposcope for cervical cancer screening and diagnosis. *PLoS One*, **13**, e0192530.

Mueller JL, Asma E, Lam CT, et al (2017). International image concordance study to compare a point-of-care tampon

colposcope with a standard-of-care colposcope. *J Low Genit Tract Dis*, **21**, 112–9.
Mueller JL, Lam CT, Dahl D, et al (2018) Portable Pocket colposcopy performs comparably to standard-of-care clinical colposcopy using acetic acid and Lugol's iodine as contrast mediators: an investigational study in Peru. *BJOG*, **125**, 1321–9.
Nahar KN, Nessa A, Shamim S, et al (2011). Role of VIA in cervical cancer screening in low-resource countries. *Mymensingh Med J*, **20**, 528–35.
Nessa A, Wistrand C, Begum SA, et al (2014). Evaluation of stationary colposcope and the Gynocular, by the Swede score systematic colposcopic system in VIA positive women: a crossover randomized trial. *Int J Gynecol Cancer*, **24**, 339–45.
Ngonzi J, Bajunirwe F, Wistrand C, et al (2013). Agreement of colposcope and Gynocular in assessment of cervical lesions by Swede score: a randomized, crossover pilot trial. *J Low Genit Tract Dis*, **17**, 372–7.
Oberoi SS (2015) .Updating income ranges for Kuppuswamy's socio-economic status scale for the year 2014. *Indian J Public Health*, **59**, 156.
Poli UR, Bidinger PD, Gowrishankar S (2015). Visual Inspection with Acetic Acid (VIA) Screening Program: 7 Years Experience in Early Detection of Cervical Cancer and Pre-Cancers in Rural South India. *Indian J Community Med*, **40**, 203–7.
Quinn M, Babb P, Jones J, et al (1999). Effect of screening on incidence of and mortality from cancer of cervix in England: evaluation based on routinely collected statistics. *BMJ*, **318**, 904.
Ranga R, Rai S, Kumari A, et al (2017). A comparison of the strength of association of Reid Colposcopic Index and Swede Score with cervical histology. *J Low Genit Tract Dis*, **21**, 55–8.
Sankaranarayanan R, Basu P, Wesley RS, et al (2004). Accuracy of visual screening for cervical neoplasia: Results from an IARC multicentre study in India and Africa. *Int J Cancer*, **110**, 907–13.
Reports | TNHSP [Internet]. Available from: http://tnhsp.org/project/reports Accessed on 26 Nov 2020.
Walmer DK, Merisier D, Littman E, et al (2004). Portable colposcopy in low-resource settings. *J Acquir Immune Defic Syndr*, **37**, 167-70.
WHO | Prevention of cervical cancer through screening using visual inspection with acetic acid (VIA) and treatment with cryotherapy [Internet]. WHO. Available from: https://www.who.int/reproductivehealth/publications/cancers/9789241503860/en/ [Accessed on 28 Nov 2020].