

CLINICAL ARTICLE

Gynecology

A pilot study of upcycled smartphone-based colposcopy for visual inspection of cervix performed by community healthcare workers in rural Vietnam

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Funding information

Community Chest of Korea; Korea International Cooperation Agency

Abstract

Objective: This study assessed the feasibility of smartphone-based colposcopy (SBC) for visual inspection of the cervix by community healthcare workers in low-resource areas.

Methods: This was a retrospective study conducted in community villages in rural Vietnam, where 177 participants were enrolled for a cervical cancer screening. Cervical images were obtained by pre-trained community healthcare workers using a portable, upcycled SBC (Samsung Galaxy Note 20). Images were taken before and after the visual inspection after acetic acid (VIA) examination. Captured images were stored on a web server through an Android-based application and later reviewed independently by two experienced gynecologists. Image quality was assessed, and kappa statistics were calculated for the measurement of agreement in VIA findings.

Results: Cervical images of 177 women obtained between July and August 2020 were analyzed. The mean age of women was 42 ± 9.1 years, and 20.3% were postmenopausal. The percentage of adequate visibility of the squamocolumnar junction (SCJ) in the captured images was 83.1%. The kappa value for interobserver reliability was 0.61 for VIA positivity agreement between the two gynecologists. Image clarity was rated as average or above in 77.3%. The reasons for suboptimal clarity were poor focusing (15.3%), inadequate SCJ visibility (18%), and obscuring of the transformation zone due to blood (11.3%), discharge (14.7%), or artifacts such as intrauterine devices or polyps (5.1%).

Conclusion: Upcycled SBC was feasible when performed by pre-trained healthcare workers in a low-resource setting. VIA findings by SBC showed adequate agreement between two independent assessments, suggesting its potential as a method to aid cervical cancer screening.

KEYWORDS

colposcopy, community health worker, mobile applications, screening, smartphone, uterine cervical neoplasms

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1 | INTRODUCTION

Cervical cancer remains a worldwide burden, especially in low-income and middle-income countries (LMICs) where 90% of cervical cancer deaths occur.¹ Despite the World Health Organization (WHO) recommendations of human papillomavirus (HPV) DNA detection as the primary screening test rather than visual inspection with acetic acid (VIA) or cytology, health systems in developing countries are not adequately equipped to effectively implement screening programs.² In fact, only 9%–11% of women aged 30–49 years in LMICs have been screened during their lifetime compared with 83% of women in high-income countries, highlighting the wide disparities in screening coverage worldwide.³ Therefore, VIA remains as an affordable screening or triage method in many low-resource settings. However, VIA assessment by the naked eye can be a highly subjective test with low performance if conducted with limited training or quality control.⁴

To overcome these issues and increase screening rates, the use of smartphone technology is becoming popular to aid performance and detection of abnormal lesions during conventional VIA or colposcopy.^{5–7} If technical training in the handling of the mobile device and VIA is possible, a smartphone camera could theoretically provide greater vision through magnification and illumination compared to the naked eye alone. In addition, when interpretation is not available by the local healthcare personnel, the captured images can undergo objective analysis using telemedicine. Quality control and education might also be possible when incorporating this technology, and a few studies have tested the intra-observer agreement between the colposcopists by reviewing the captured cervical images.^{5,7}

Although the digital aid in capturing cervical images might offer support for community healthcare workers in rural areas of the world, smartphone cameras might not be attainable due to the expense. Interestingly, more than five billion mobile phones worldwide were reported to be discarded or stashed away in 2022.⁸ Therefore, we made use of the Galaxy Upcycling Program of Samsung Electronics, which has developed an upcycled SBC device with the older versions of Galaxy. The aim of this pilot study was to evaluate the feasibility of the device for visual inspection of the cervix performed by the community healthcare workers in rural villages of Vietnam. Additionally, the agreement of VIA findings of captured images reviewed by two external experts was assessed.

2 | MATERIALS AND METHODS

This retrospective study was part of the Community-Based Screening of Chronic Disease using Upcycled Smartphone Project in Quang Tri Province of Vietnam. This project was conducted from March 2019 to August 2020 by the Department of Medical Humanities and Social Sciences at Yonsei University, Korea, in partnership with the Circular Economy Lab at Samsung

Electronics. Its objective was to develop a screening platform for cervical cancer and diabetic retinopathy in countries that lack adequate healthcare services. Women in 15 rural community villages of Quang Tri, Vietnam, were invited for cervical cancer screening, with concomitant Papanicolaou (PAP) smear and cervical cancer education. Consent was obtained from all women before participation. Women aged 20–65 years received visual inspection on acetic acid (VIA) using the portable SBC in their community health centers. Images of 177 women from between July and August 2020 were analyzed. Women with a previous history of cervical conization and those who had undergone a hysterectomy or were pregnant at the time of examination were excluded. The study was approved by the Institutional Review Board of Yonsei University (IRB No. 2019-2733-007).

2.1 | Smartphone-based colposcopy training and examination

Cervical images were obtained by pre-trained community healthcare workers using SBC. Prior to the initiation of this project, midwives were first trained to learn the techniques of colposcopy examination, supervised by the gynecologists at Hue University, Vietnam. The examination skill was then taught and passed on to the community health workers through training programs. A 2-day training course included lectures and practical sessions using vaginal simulators. A structured manual was provided outlining the procedural steps for obtaining correct cervical images, preparation, and application of acetic acid.

Relevant clinical factors were obtained from each woman and entered into the application within the smartphone device. They were age, parity, weight, height, last menstruation date, mode of delivery, and presence of gynecologic symptoms. Cervical images were taken before and after the application of acetic acid. Healthcare workers were trained to hold the smartphone at a 15-cm distance from the vulva using a tripod (Figure 1) and use the zoom-in function set to 1.6 to 2.2× according to the size of the cervix. Sample standard images of colposcopy were shown to advise the size of the entire cervix to occupy approximately two-thirds of the photo image. Care was taken to avoid any discharge, blood, or protruding vaginal wall in the image, which could obscure the visualization of the cervical transformation zone. A concomitant Papanicolaou smear was performed when feasible. Captured images were stored on a web server through an Android-based application.

2.2 | Upcycled smartphone-based colposcopy device

The development of mobile-based colposcopy was part of the Galaxy Upcycling program of Samsung Electronics, initiated in 2017. The Samsung Galaxy version J6 was used as the low-cost prototype in the early stages of development in 2019, the Samsung Galaxy J6 model used as a low-cost prototype. It was then upgraded to



FIGURE 1 Upcycled smartphone-based colposcopy. (a) First prototype of swing type smartphone-based colposcopy. (b) Training of community health workers for obtaining colposcopy images. (c–e) Upgraded version of tripod type smartphone-based colposcopy with light-emitting diode (LED) flashlight.

the Galaxy Note 20 version for use as a portable colposcope. The first prototype J6 had an illuminating lens in front of the phone and was handled as a swing type device (Figure 1a,b). Then, a light-emitting diode (LED) flashlight was placed around the camera in four directions to prevent shading of the cervix without affecting the path for obtaining the image (Figure 1c). Therefore, sufficient illumination conditions were secured without image loss due to reflection. To overcome the issues of magnification with low-cost terminals, Galaxy S, Note 9, and Note 20 models were used consecutively, which allowed high-resolution images with 10 times zoom-in function, even without additional lenses. To maintain the consistency of the image quality, those images captured with Galaxy Note 20 were analyzed in this study.

2.3 | Data evaluation

For each woman screened with VIA by SBC, at least two of the best images each before and after applying acetic acid were obtained (Figure 2). All images were later reviewed independently by two experienced gynecologists from Vietnam (Hue University) and Korea (Dongguk University). Pap smear results were blinded, and only images were provided for review. VIA was considered positive

if acetowhite lesions were observed in or close to the transformation zone. Both gynecologists were experienced in colposcopy and were informed to use the definition of VIA positivity according to the WHO's International Agency for Research on Cancer (IARC) manual.⁹ In detail, the definition of VIA positivity is dense acetowhite areas in the transformation zone (TZ) or columnar epithelium with well-defined margins, the entire cervix appearing dense acetowhite, leukoplakia becoming acetowhite, and congenital TZ appearing acetowhite. Image quality was assessed for visibility of the entire cervix and the transformation zone, acetowhitening, and clarity. Image clarity was rated with a scale of 1–5 (1=very poor, 2=poor, 3=average, 4=good, and 5=excellent). A score of 3 (average clarity) was predefined for an image that is assessable for VIA interpretation. If the clarity score was 3 (average) or less, the cause of subnormal image clarity was recorded. The kappa value (κ) was used to evaluate the agreement of VIA findings between two gynecologists. Kappa values of 0.21–0.40 represent poor to fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and 0.80 or greater excellent agreement between the decision for VIA positivity. Descriptive statistics were used for demographic data. IBM SPSS software version 23.0 (SPSS, Chicago, IL, USA) was used for statistical analysis. $P < 0.05$ was regarded as statistically significant.

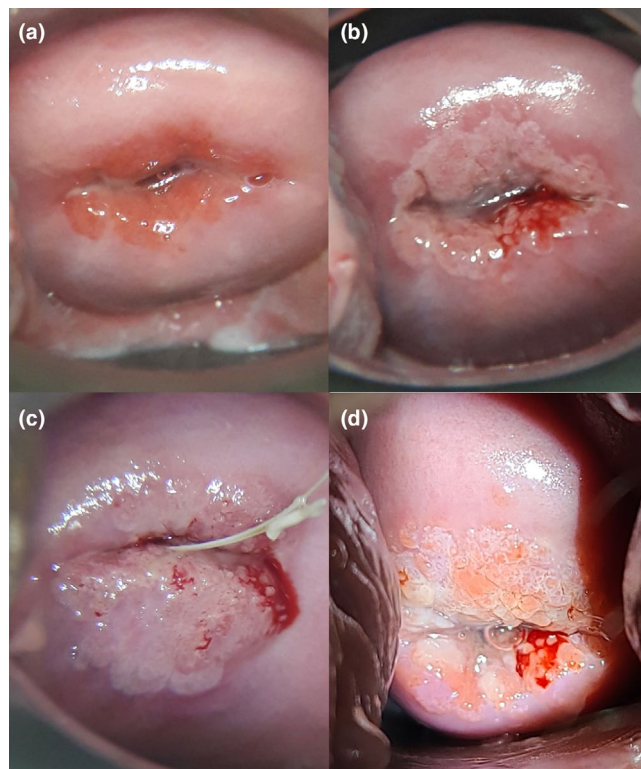


FIGURE 2 Smartphone-based colposcopy images of the uterine cervix. (a, b) Before and after acetic acid application. (c, d) Positive visual inspection of acetic acid cases.

3 | RESULTS

The cervical images of 177 women obtained between July and August 2020 with the Galaxy Note 20 were analyzed for this study. The mean age of women was 42 ± 9.1 years, with a range of 20–63 years (Table 1). The mean number of parity was 2.9, and 76.8% of women had undergone vaginal delivery. Approximately 20.3% of women were postmenopausal at the time of examination. Excluding two missing slides, most (92.1%) of women had normal cervical cytology on PAP smear. Ten (5.6%) and two (1.1%) women had atypical squamous cells of undetermined significance (ASCUS) and atypical squamous cells-cannot exclude high-grade squamous intraepithelial lesions (ASC-H), respectively. However, none of the two ASC-H cases had VIA positivity. Among 10 patients with ASCUS, two cases had positive VIA findings interpreted by the Korean gynecologist, whereas three cases were assessed as VIA positive by the Vietnamese gynecologist.

The entire cervix was visible in 57.0% (Table 2), and a total of 83.1% had partial or complete visibility of the squamocolumnar junction (SCJ). Twenty-nine out of 177 women (16.4%) had unsatisfactory findings due to inadequate SCJ visibility. When image clarity was rated, 77.3% of images assessed as 'average' and above. The reasons for the image clarity rate of 3 (average) or less were poor image focus (15.3%), inadequate SCJ or lesion visibility (18%), obscuring of the transformation zone due to blood (11.3%), discharge (14.7%), or artifacts such as an intrauterine device string or polyps

TABLE 1 Patient characteristics.

Characteristics	N=177
Age, mean (SD)	42 (9.167)
BMI, mean (SD)	22.3 (2.49)
Parity, mean (SD)	2.9 (1.43)
Age at first sexual intercourse, mean (SD)	23.1 (3.25)
Mode of delivery, n (%)	
Vaginal	136 (76.8)
Cesarean section	8 (4.5)
Menopause, n (%)	36 (20.3)
Cervical cytology, n (%)	
Missing	2 (1.1)
Normal	163 (92.1)
ASCUS	10 (5.6)
ASC-H	2 (1.1)

Abbreviations: ASCUS, atypical squamous cells of undetermined significance; ASC-H, atypical squamous cells-cannot exclude high-grade squamous intraepithelial lesion; BMI, body mass index; SD, standard deviation.

(5.1%). VIA positivity was independently assessed by two gynecologists experienced in colposcopy. VIA was considered positive according to the criteria suggested by the IARC. As a result, the kappa statistic for inter-observer reliability between the two gynecologists was 0.61, indicating substantial agreement for VIA positivity in the images.

4 | DISCUSSION

The results of this pilot study suggest that the upcycled smartphone-based approach for VIA is feasible when performed by non-medical personnel in low- and middle-income countries. The Galaxy SBC is portable, affordable, and feasible, as shown in this study, where all examinations were done by pre-trained community healthcare workers of rural Vietnam. It also provides the potential for remote assessment of cervical images, yielding a substantial agreement (Cohen's $\kappa=0.61$) of VIA image interpretations between two independent physicians.

Colposcopy is a critical step in the diagnosis of premalignant cervical lesions. It is usually done in cases of abnormal cervical cancer screening results to identify the lesion and perform a targeted biopsy. However, the WHO recommendations for cervical screening still include VIA due to many known setbacks of conventional colposcopy in underserved areas.¹⁰ There are two main rationales for the use of the smartphone-based VIA approach in this study. First, HPV testing or cervical cytology is not feasible in many LMICs, despite the recent WHO guidelines putting HPV as the primary cervical cancer screening. Moreover, if HPV testing replaces cytology in accessible regions, there might be higher referral rates, requiring an increase in colposcopy capacity and quality control systems. Therefore, VIA might remain as the most

TABLE 2 Smartphone-based colposcopy findings.

Characteristics	N = 177
VIA positive, n (%)	
Gynecologist 1	9 (5.1)
Gynecologist 2	4 (2.3)
VIA negative, n (%)	168 (94.9)
SCJ visibility, n (%)	
No	29 (16.4)
Partially	64 (36.2)
Completely	83 (46.9)
Visibility of entire cervix on image, n (%)	
No	23 (13.0)
Yes	154 (57.0)
Image clarity, n (%)	
Very poor	3 (1.7)
Poor	37 (20.9)
Average	73 (41.2)
Good	50 (28.2)
Excellent	14 (7.9)
Reason for image clarity of average or less, n (%)	
Focus	27 (15.3)
Inadequate visibility of SCJ or lesion	32 (18.1)
Blood	20 (11.3)
Discharge	26 (14.7)
Artifact (polyp, IUD string)	9 (5.1)

Abbreviations: IUD, intrauterine device; SCJ, squamocolumnar junction; VIA, visual inspection on acetic acid.

affordable screening method in resource-limited areas. In this context, the second reason for implementing the smartphone-based approach was to test the feasibility of VIA examination through training of the available healthcare workers. If training is possible and yields adequate image quality, remote assessment might be the next step to detect positive VIA lesions. Tanaka et al. suggested that smartphone colposcopy could be a good alternative to conventional colposcopy, reporting substantial agreement between histologic diagnoses for cervical intraepithelial neoplasia and colposcopy findings (κ -value 0.67, 95% CI, 0.43–0.90).¹¹ However, VIA cannot be the sole method for primary screening but could be used as a triage tool for positive HPV cases and as a diagnostic test to aid biopsy. Our next plan is to incorporate HPV testing combined with this smartphone-based VIA approach. It is important to note that a high proportion of women with a positive HPV test will not necessarily have cervical pathology. In this regard, many countries would still have to use VIA to triage HPV-positive women.

The differences of this study from the already existing data using the mobile-based approach for cervical examination are as follows. First, the target population of the cervical cancer screening project was the general population of rural villages of Vietnam, who do not

have adequate access to screening. Therefore, SBC was not used as triage for women with abnormal screening tests. Although the recent accessibility of cervical cytology in some villages provided concomitant PAP smear results, they were blinded to the two gynecologists that interpreted the VIA findings in this study. The purpose of this study was not to compare the cytology or histology results with the SBC findings but to evaluate the feasibility of VIA using the SBC approach performed by the non-medical personnel. Second, upcycled smartphones with an illuminating light source were developed and used in this study. The first and other similar studies that evaluated the utility of smartphones to detect cervical lesions used iPhone 5s and 8s.^{5,7,11} However, the use of smartphones could be another burden in resource-poor areas if not accessible or affordable. Although the average selling price of smartphones in Africa has reduced significantly to below US\$100 in recent years, the cost remains unaffordable for many.¹² Galaxy smartphones have higher distribution rates in LMICs due to wide global marketing networks, which is also advantageous for timely service management. The up-cycling program by Samsung Electronics aimed to repurpose (upcycle) old smartphones into medical equipment and to provide greater access to ophthalmic and gynecologic health care in underserved communities around the world. Another goal of this program was to divert e-waste from landfill while providing innovative medical solutions to support the 2030 Agenda for Sustainable Development Goals.⁸ Hence, the usage of upcycled smartphones could be a sustainable method for continuous service delivery.

When capturing images using the smartphone-based platform, it is difficult to assess the colposcopic features suggested by the International Federation of Cervical Pathology and Colposcopy criteria.¹³ There are no guidelines on how to assess smartphone-based images in patients with inadequate visibility of the squamous columnar junction (SCJ). These images will be challenging to interpret through remote assessments, lowering the sensitivity of diagnosis despite the integration of recent artificial intelligence technology.¹⁴ In a recent multicenter ESTAMPA study where the accuracy of conventional colposcopy was evaluated as a triage method in HPV positive women, age and poor visibility of the transformation zone were reported to be the key factors associated with reduced triage accuracy.¹⁰ Interestingly, the subanalysis of the same study evaluating the performance of VIA for triage showed high sensitivity for cervical pre-cancer detection.¹⁵ The authors admitted that VIA will be challenging due to high variability in performance and the need for training and supervision by the providers. In our study, approximately 16% of the patients had no SCJ visibility. However, the reasons for partially visible SCJ cases were mostly correctable causes, which could be improved with widening of the speculum and wiping out the discharge or blood more carefully. In terms of training, the time needed to be proficient with the colposcopy device might depend on the health workers' medical knowledge, previous experience, and the medical delivery system. In this study, we implemented a training of trainers approach to train the community healthcare workers. They are non-physician personnel under the Vietnamese medical system, who are officially permitted and designated to each village health post to provide health screening exams,

vaccination, and education for the villagers. Although the structured training course for colposcopy was 2 days, gynecologists and project managers at each community center helped with troubleshooting for the device and supervised the performance of the users during the early phase of the project (4 weeks). Because focusing and zooming features are easier to control on smartphones compared with a conventional colposcopy device, obtaining images was not difficult according to the user feedback and the assessment of captured images. In a similar smartphone-based VIA study in semi-rural Tanzania, five non-physician providers were trained by sending the images through a smartphone application and receiving off-site real-time feedback from regional experts.¹⁶ After 1 month of training, the agreement rate between trainees and experts was 96.8%. Maintaining competencies of VIA is a challenging issue, as short-term VIA training might not guarantee skill retention, especially in an environment away from the medical facilities. Our feasibility result can be referenced when implementing SBC in low-resource settings similar to our project site.

A limitation of this study is the selection bias in using the most recent colposcopy images (those taken in 2020) for analysis. The reason for this is mainly due to the usage of more recent upcycled smartphone versions for enhanced image quality. Because the limitation of VIA screening lies in the variation in sensitivity (41%–92%) caused by inconsistent quality in obtaining and interpreting the findings,¹⁷ better smartphones with enhanced camera and zoom-in features could improve image quality. Whether different specification of smartphones might change the quality of VIA images and interpretation is another area of research. Another limitation of this study is the lack of triage results in women with positive VIA findings. Although we have referred women with abnormal high-grade cytology or positive VIA to the relevant medical centers, follow-up histopathology results and outcomes could not be accessed for this study due to the following COVID pandemic. Finally, only two experienced gynecologists reviewed the cervical images for VIA interpretation. Moreover, the interobserver agreement of image quality was not assessed due to the lack of an objective, validated tool to assess image contrast, focus, or brightness.^{6,18} Instead, the overall percentage of average or above quality image that is needed for the interpretation of VIA was analyzed, which was over 77%. Further studies are needed to objectively rate the quality of images, especially when taking into account that remote image-based triage along with HPV testing for cervical cancer screening is expected to increase with the advancement of technology. Nonetheless, the study has shown that saving all images in the Android application within the smartphone device is feasible and convenient. In addition, the process of downloading and sending the images was achievable, along with remote VIA assessment by experts. The incorporation of telemedicine in the area of cervical cancer screening is a promising field that requires further validation.

5 | CONCLUSION

The use of SBC was found to be feasible for examination when performed by pre-trained healthcare workers in low-resource setting.

There was an adequate agreement between the VIA assessment based on the captured images using the upcycled smartphone technology.

AUTHOR CONTRIBUTIONS

GWY: conceptualization, data curation, methodology, formal analysis, investigation, writing – original draft, review and editing. **JL:** conceptualization; methodology, resources; software, writing – review and editing. **KY:** conceptualization; methodology, resources; software, writing – review and editing. **CHL:** conceptualization, data curation, methodology, supervision, writing – review and editing. **NVQH:** conceptualization, methodology, supervision, review and editing. **MTV:** conceptualization, methodology, supervision, review and editing. **SY:** conceptualization, data curation, methodology, formal analysis, funding acquisition; investigation, writing – original draft, review and editing.

FUNDING INFORMATION

This research was supported by Community Chest of Korea and Higher Education Initiative Project of Korea International Cooperation Agency.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest or financial ties to disclose.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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How to cite this article: Yim GW, Lee J, Yang K, et al. A pilot study of upcycled smartphone-based colposcopy for visual inspection of cervix performed by community healthcare workers in rural Vietnam. *Int J Gynecol Obstet*. 2025;168:518-524. doi:[10.1002/ijgo.15867](https://doi.org/10.1002/ijgo.15867)