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Review Article

Advancing Cervical Cancer Care: A Comprehensive Study of Screening Approach for Tribal Women in Sub-Saharan Africa and Asia

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Abstract

Background: Cervical cancer is one of the leading causes of cancer-related mortality among women in developing regions, particularly within tribal populations of Sub-Saharan Africa and Asia. This study aimed to evaluate existing screening strategies in tribal communities, compare them with global best practices, and explore the feasibility of smart colposcopy as an effective screening tool in low-resource settings.

Methods: A mixed-methods approach was employed, combining systematic literature review 2000-2024, case study analysis, and technical evaluation. Data were collected from peer-reviewed journals, healthcare databases, and open-access medical image repositories. The diagnostic utility and usability of smart colposcopy using the Eva System were assessed. Advanced image processing techniques, including CNN-based detection and partial convolution inpainting, were applied to improve visual clarity by mitigating artifacts like specular reflection.

Results: Findings reveal significant screening barriers in tribal regions, such as fear, stigma, and infrastructural deficits. Compared to structured programs in developed countries, tribal areas show lower compliance. Smart colposcopy demonstrated high potential for remote screening due to its portability and real-time AI support. Image quality enhancements improved diagnostic accuracy.

Conclusion: Smart colposcopy, integrated with awareness initiatives and supportive policies, offers a scalable solution to improve early detection and reduce cervical cancer mortality in tribal and underserved populations.

Keywords: Cervical cancer screening; Tribal populations; Smart colposcopy; Image processing; Healthcare disparities

Introduction

Cervical cancer is a leading cause of cancer-related deaths among women, particularly in low- and middle-income countries. Globally, it accounted for approximately 604,237 new cases and 341,831 deaths in 2020 alone, with the highest burden found in Sub-Saharan Africa and parts of Asia (1,2). The disease is largely preventable through routine screening and vaccination, yet tribal populations continue to face severe disparities in access to both. In many tribal and rural communities, limited education, poverty, cultural taboos, and geographic isolation significantly

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hinder women's participation in screening programs (3,4). The cervical cancer incidence from 1990 to 2019 across various regions notably, East Asia, South Asia, Central Asia, Eastern Sub-Saharan Africa, Southern Sub-Saharan Africa, Western Sub-Saharan Africa, and North Africa and the Middle East witnessed an increase in cases in comparison to other developed countries (5). In contrast, North America, Central Europe, Eastern Europe, and Western Europe observed a decline in cervical cancer incidence during the same period (6). Fig. 1 illustrates the global incidence of cervical cancer from 1990 to 2019, revealing a substantial increase in developing countries like Sub-Saharan Africa and Asia (7).

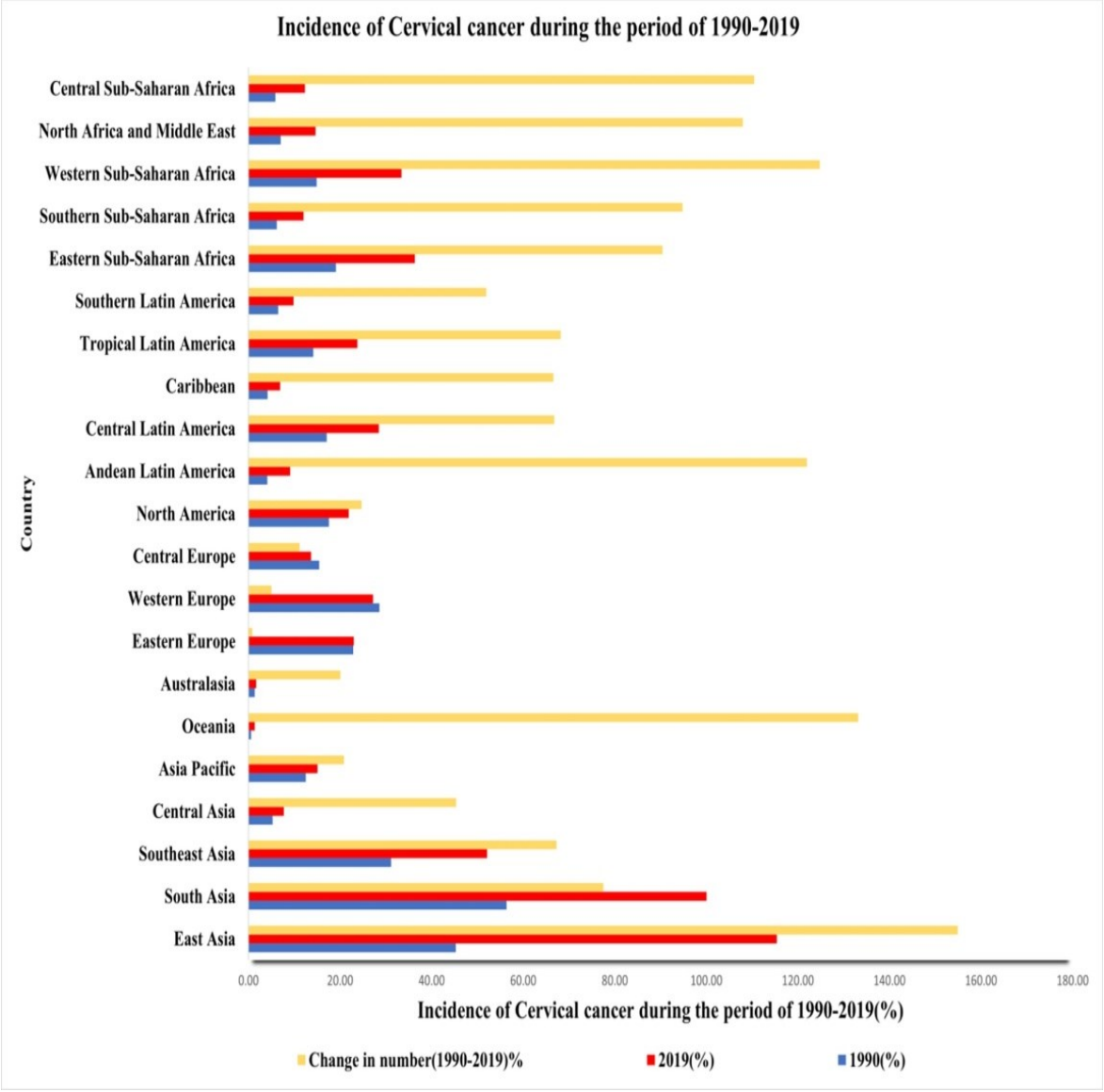

Fig. 1: Incidence of cervical cancer during the period of 1990-2019

The persistent rise in cervical cancer cases in developing countries is often attributed to limited healthcare infrastructure, poverty, lack of education, cultural taboos, and geographic isolation (8). Tribal populations, in particular, face unique challenges that severely limit their participation in

screening programs. For example, a study conducted among HIV-positive women in Lagos, Nigeria, found that while over 79% were willing to participate in screening, cost and cultural barriers were major deterrents (9). Similarly, educational programs tailored for Maasai women in Tanzania—delivered in local language and using 3D models— demonstrated that context-sensitive approaches can significantly improve awareness and screening participation (10). Recognizing these disparities, developed nations have implemented national initiatives like the NBCCEDP in the United States, supporting screening efforts across states, territories, and tribal communities (11). However, such comprehensive programs remain scarce in many low-income regions. Additionally, the complexity and cost of traditional screening tools—like Pap smears and HPV tests—further hinder widespread adoption in rural and tribal settings.

To address these disparities, this study explores the potential of smart colposcopy technologies, particularly the EVA System by MobileODT, in enhancing cervical cancer screening among tribal populations. These AI-enhanced, portable diagnostic devices allow for point-of-care screening with minimal infrastructure, making them especially suitable for use in remote and underserved areas. The introduction of such technologies holds significant promise for improving early detection rates in tribal communities, thereby potentially reducing cervical cancer incidence and mortality. However, a major technical challenge limiting the diagnostic accuracy of smart colposcopy is specular reflection—bright white spots on cervical images caused by light reflecting off moist tissue (12,13). These reflections can obscure critical details and hinder the effectiveness of automated image analysis. In this study, we address this challenge by applying image processing techniques—specifically convolutional neural network (CNN)-based detection and partial convolution inpainting—to enhance the diagnostic quality of images captured using smart colposcopy devices.

By addressing both the accessibility barriers and technical limitations, this study aimed to demonstrate how smart colposcopy can serve as a game-changing tool in cervical cancer screening, especially for tribal populations who are often underserved by traditional healthcare systems.

Methods

The research design employed in this study is mixed-methods research design that integrates qualitative and quantitative methodologies to examine holistically cervical cancer screening practices among tribal populations in Sub-Saharan Africa and Asia. The research is structured around five core objectives: (i) to evaluate cervical cancer screening programs implemented for tribal women in resource-limited settings; (ii) to comparatively analyze screening protocols adopted in developed countries; (iii) to introduce and evaluate a novel screening paradigm utilizing smart colposcopes; (iv) to identify technical challenges in the application of smart colposcopy, particularly those related to image quality and processing; and (v) to propose preventive strategies for reducing mortality rates among underserved tribal populations.

Data Collection and Sources

Data were collected from peer-reviewed journals, healthcare databases, and open-access medical image repositories covering the period from 2000 to 2024. A systematic literature review was conducted to identify studies related to cervical cancer screening in tribal populations of Sub-Saharan Africa and Asia, as well as screening protocols in developed countries. Keywords used included "cervical cancer screening," "tribal populations," "smart colposcopy," "Pap smear," and "healthcare disparities."

Smart Colposcopy Evaluation

To evaluate a novel cervical cancer screening paradigm in underserved tribal populations of developing nations, this study utilized the Enhanced Visual Assessment (EVA) system, a smart digital colposcope developed by MobileODT (14). The EVA system is a portable, AI-powered

visual screening tool that integrates a 13MP high-resolution camera, 16x optical zoom, autofocus, and dual lenses, and is connected to a smartphone through the EVA mobile application. This allows for real-time image capture, cloud-based storage, and remote expert diagnosis (15,16). The case studies were analyzed from multiple screening programs that deployed the EVA system in both mobile screening camps and stationary clinics. The study reviewed data from 1,155 patients screened across 316 mobile clinics, where 261 women were identified with abnormal cervical lesions and 25 received cryotherapy. In stationary clinics, 89 women were diagnosed with abnormal lesions and 36 were treated with cryotherapy (17). A separate screening program in Kenya using the EVA system in combination with Visual Inspection with Acetic Acid (VIA) screened 824 women in one week. The evaluation included quantitative assessment through diagnostic accuracy comparisons with conventional methods such as the Pap smear and traditional colposcopy, as well as qualitative analysis involving demographic surveys to assess awareness, literacy, and social acceptability.

Technical Image Processing Methods

The implementation of smart colposcopy involves a 13MP resolution camera for capturing cervical images at a working distance magnification ranging from 250mm to 400mm. This device is equipped with a 6000K 3W LED light and a wire grid polarizer to enhance focus on the cervix region and reduce glare (18). But still the images are affected by the artifacts called specular reflection which appears as the acetowhite region on the images as represented in the Fig. 2 (19).

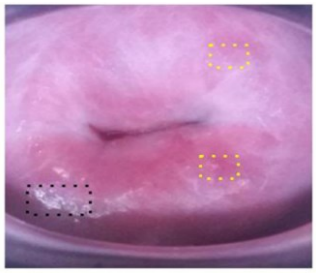

Fig. 2: Specular reflection on cervix images (black dotted box) captured through the smart colposcope collected from the Kaggle dataset. The acetowhite region (yellow dotted box) on the cervix looks similar to the specular reflection.

Detection of Specular Reflection

Specular reflection, characterized by bright white pixels in cervix images, was identified using the RGB color space. The RGB color space represents Red, Green, and Blue color values, each ranging from 0 to 255. Specular reflection, appearing as white pixels, typically falls within the intensity range of 191 to 255. Pixels falling within this range were selected and rescaled to zero. A Convolutional Neural Network (CNN) was then trained using these selected pixels to detect specular reflections in smart colposcopy cervix images. The CNN model comprises two input layers, f our hidden layers, and two output layers using the sigmoid activation function. To prevent overfitting, batch normalization was applied to normalize input images (20). The CNN model classifies cervix images into two labels: specular reflection regions and non-specular regions.

Elimination of Specular Reflection

To address the missing pixels resulting from the removal of specular reflections, a partial convolution inpainting method was employed. This method involves partial convolution operations and mask updates to refill missing pixels and improve image quality. The input image (specular reflection-detected image) is transformed into a binary mask, where 0 denotes missing pixels and 1 denotes valid pixels in the image. The partial convolution operation is determined using the equation (1)

$$x' = \begin{cases} W^T\,(I_{out} \odot M)\,\frac{Sum(1)}{Sum(M)}, if\ sum(M) > 0 \\ 0, Otherwise \end{cases} \quad [1]$$

Here, W represents the weight of the partial convolution operation and M represents the masked image in which the reflections are removed. The element-wise multiplication $\odot$ is used to refill

missing pixels (21). The partial convolution inpainting process is iterated until the entire mask is updated.

Ethical Considerations

This study does not involve direct experimentation with human or animal subjects. All data used in the research were sourced from publicly available datasets, published reports, and anonymized image repositories. Appropriate referencing and academic integrity have been maintained throughout in compliance with ethical standards.

Results

This section presents the findings from the evaluation of cervical cancer screening programs in tribal and developed populations, the deployment outcomes of smart colposcopy using the EVA system, technical improvements in image quality through CNN-based processing, and a comparative analysis of various screening methods.

Screening Performance in Tribal and Developed Populations

The evaluation of cervical cancer screening programs revealed significant disparities between tribal populations and developed countries. In tribal regions of Sub-Saharan Africa and Asia, participation rates remained critically low despite multiple screening campaigns. In developed countries with structured screening programs, participation rates consistently exceeded 70%, while tribal regions showed rates below 20% in many communities.

Image Quality Enhancement Results

The application of CNN-based detection successfully identified specular reflections in cervical images captured by the EVA system. The CNN model achieved high accuracy in classifying cervix images into specular reflection regions and non-specular regions (Fig. 3B). Following detection, the partial convolution inpainting method effectively refilled missing pixels, improving overall image quality and diagnostic clarity (Fig. 3C). These enhancements addressed the technical challenge of specular reflection that can mimic acetowhite regions and confuse diagnostic assessment.

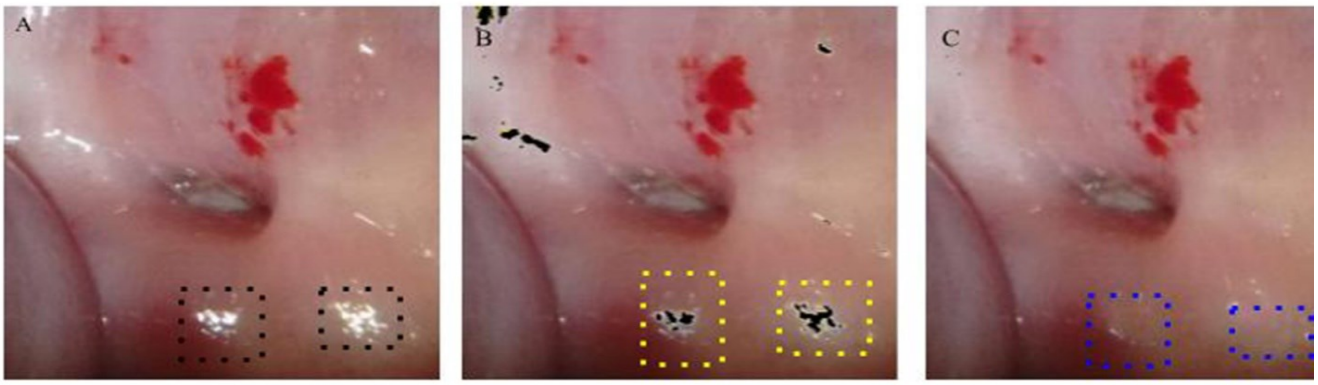

Fig. 3: (A) Specular reflection labeled on the cervix image captured through the EVA system (black box). (B) Detected and removed specular reflection from the cervix image using a convolutional neural network (yellow box). (C) Refilled the removed specular reflection using the partial inpainting method.

Comparative Analysis of Screening Methods

The Table 1. summarizes the comparative characteristics of common screening methods, focusing on their ease of use and effectiveness. Among these methods, smart colposcopy stands out as the most adaptable for remote and resource-constrained environments.

Table 1: Comparative Inference of screening methods in developed nations

Method	Ease	Effectiveness
Questionnaires	Non-invasive, easy to administer, can be digital or paper-based	Identifies behavioral, economic, and psychological barriers to screening
Cervical Cytology	Slightly invasive, requires trained personnel and lab infrastructure	Gold standard for early detection of cellular abnormalities, reduces long-term incidence
Smart Colposcopy	Portable, non-invasive, user-friendly	AI-enhanced diagnostics improve accuracy and accessibility, especially in underserved populations

A detailed comparison of various cervical cancer screening techniques (Table 2) outlines the advantages and limitations of the Pap smear, liquid-based cytology, traditional colposcopy, and smart colposcopy. The table highlights that smart colposcopy is painless, cost-effective, easily portable, and highly accurate, making it particularly suitable for use in remote and resource-constrained areas.

Table 2: Comparison of Cervical Cancer Screening Methods

Feature	Pap Smear	Liquid-Based Cytology	Colposcopy	Smart Colposcopy
Clinical Procedure	Invasive & Painful	Painless	Painless	Painless
Cost	High	Medium	High	Low
Portability	Less	Low	Not Portable	Portable
Time Efficiency	More	Medium	High	Low
Infrastructure Requirement	High	Medium	High	Low
Manpower Requirement	High	Medium	High	Low
Accuracy in Cancer Detection	High	High	High	High
Patient Comfort	Low	Medium	Medium	High

Discussion

This study highlights the persistent disparities in cervical cancer screening between tribal populations in low-resource settings and their counterparts in developed nations. Despite numerous awareness initiatives, tribal women face compounded challenges including geographic isolation, cultural taboos, limited healthcare access, and a deep-rooted fear of invasive procedures.

Screening Barriers in Tribal Populations

The studies conducted among tribal and non-tribal populations in the Andaman and Nicobar Islands targeted married women aged 20 to 60 years presenting with symptoms such as vaginal discharge and abnormal bleeding. Among the 110 women screened, results showed HPV16 infections in four non-tribal women and one HPV18 infection in a tribal woman (22).

A more extensive screening program conducted from July 2014 to June 2017 in Udupi district, Karnataka, targeted the Koraga, Marathi Naika, and Malekudiya tribal communities. Among the 1,140 women screened, medical examination revealed that 12.4% had microbial infections, 23.6% showed cervical changes, and 2% exhibited cervical abnormalities (23,24). In Maharashtra's Palghar District, a pre- and post-assessment study involving 76 tribal women demonstrated significant knowledge gaps regarding cervical cancer and HPV vaccination (25). In Gujarat's Aravalli district, where 22% of the population identifies as tribal, an empirical investigation revealed that only 2% of healthcare institutions offered Pap smear tests (26). In Thailand, reported that 96.15% had undergone Pap smear testing, demonstrating higher screening uptake (27). In Akha hill tribal women had a 12.2% prevalence of abnormal Pap smear results compared to 4.5% in the urban group (28). In Phetchabun province,

64.9% of Hmong hill tribe women had undergone cervical cancer screening (29).

In Zimbabwe's Midlands Province, a study among 125 women attending traditional churches revealed widespread fear and misconceptions about Pap smears. The primary barrier to screening was the belief that the procedure was painful and invasive, leading to anxiety and reluctance to participate (30). These findings collectively underscore that tribal women in developing countries remain disproportionately affected by cervical cancer due to fear, stigma, limited healthcare infrastructure, and lack of targeted awareness campaigns.

Screening Practices in Developed Countries

In developed countries, cervical cancer screening protocols have advanced through structured public health systems, innovative technologies, and evidence-based practices. Questionnaires and interviews in developed nations help identify sociocultural, economic, and systemic barriers that may hinder participation. A study in Japan targeted unmarried sexually active women aged 20-29, revealing that cost, time constraints, and discomfort with male physicians were common reasons for non-participation (31). An awareness campaign in Riyadh, Saudi Arabia, found economic limitations to be major deterrents (32). In England, a large-scale survey identified embarrassment, lack of time, and fear of pain as major barriers, though 80% of participants adhered to regular screening (33). A survey across 29 European countries underscored the importance of institutional support and monitoring for successful implementation (34).

Cervical cytology remains the cornerstone of screening programs across the developed world. Finland implements a 5-year screening interval for women aged 30-64, with participation around 73% (35). The United Kingdom introduced a national program in 1988 for women aged 20-64, contributing significantly to reduced mortality (36). Australia transitioned from a 3-year to a 2-year screening interval, showing similar efficacy with improved cost-effectiveness (37). Egypt's use of liquid-based cytology and HPV co-testing, and Italy's consistent 3-year intervals, demonstrate adaptable cytology protocols (38,39).

Smart Colposcopy as a Transformative Solution

The introduction of smart colposcopy, particularly the EVA system, demonstrated a promising paradigm shift in cervical cancer screening. Its portability, real-time AI diagnostics, and patient-friendly features significantly increased participation rates among women who would otherwise be reluctant to undergo traditional Pap smear tests. In the Dominican Republic, MobileODT collaborated with Israel's government to screen 9,000 women in three months using the EVA system, with plans to scale up to 50,000 women (40). During a six-day screening campaign in China, 3,886 women were tested for HPV, and 168 received colposcopy with the EVA system (41). Moreover, the incorporation of deep learning techniques, such as CNN-based detection and partial convolution inpainting, successfully addressed technical issues like specular reflection—enhancing diagnostic image quality and clinical reliability. Specular reflection manifests as bright white spots on cervical images due to moisture content within the cervix tissue, which can mimic acetowhite regions and confuse diagnostic assessment. The technical solutions developed in this study effectively eliminated these unwanted bright spots, improving overall diagnostic accuracy.

Comparatively, developed countries' success in reducing cervical cancer incidence is owed to their well-structured, multi-method screening approaches supported by policy frameworks and robust healthcare infrastructure. Our comparative analysis confirmed that while Pap smears remain the gold standard, smart colposcopy emerges as a practical and scalable alternative for regions lacking laboratory support and trained personnel. This research not only showcases the feasibility of deploying smart colposcopes in tribal settings but also demonstrates the critical need to pair technology with targeted educational and infrastructure initiatives. Awareness campaigns, integration of mobile health units, and culturally sen-

sitive outreach were shown to be essential for maximizing the impact of new screening technologies.

Proposed Preventive Strategies

To reduce effectively cervical cancer mortality rates in underserved tribal populations, comprehensive, community-driven approaches are essential. Key strategies include awareness and education campaigns tailored to local languages and cultural contexts, strengthening healthcare infrastructure through mobile health units equipped with smart colposcopy devices, integration of affordable and accessible smart colposcopy technologies into routine healthcare services, encouraging regular screening and follow-up through community-based health education and incentive programs, overcoming cultural barriers by collaborating with tribal leaders and local health committees, empowering women with knowledge through health education workshops and peer support groups, and fostering collaboration between local governments, international organizations, NGOs, and private sector players to enhance resource mobilization and service delivery.

Conclusion

Smart colposcopy represents a transformative opportunity for reducing cervical cancer mortality in underserved tribal populations. By overcoming both cultural and technological barriers, it enables early detection in settings where traditional methods are impractical or underutilized. The AI-powered EVA system proved to be effective in enhancing both diagnostic accuracy and patient compliance. However, the success of this approach depends heavily on a supportive ecosystem—comprising trained personnel, reliable mobile health services, and sustained community engagement. It is crucial for public health policies to adopt inclusive strategies that integrate smart technologies with localized awareness and education campaigns. Future research should focus on longitudinal studies to track health outcomes over time, explore the cost-effectiveness of smart colposcopy integration at scale, and develop more advanced algorithms to improve further image analysis and diagnostic performance.

Journalism Ethics considerations `

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interests.

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