

# Cervical cancer data and data systems in limited-resource settings: Challenges and opportunities

Jennifer L. Drummond<sup>1,\*</sup> | Martin C. Were<sup>2,3,4</sup> | Silvina Arrossi<sup>5</sup> | Kara Wools-Kaloustian<sup>6</sup>

<sup>1</sup>National Foundation for the Centers for Disease Control and Prevention, Atlanta, GA, USA

<sup>2</sup>Department of Biomedical Informatics, Vanderbilt University, Nashville, TN, USA

<sup>3</sup>Department of Medicine, Vanderbilt University, Nashville, TN, USA

<sup>4</sup>Vanderbilt Institute for Global Health, Nashville, TN, USA

<sup>5</sup>Centro de Estudios de Estado y Sociedad/ Consejo Nacional de Investigaciones Científicas y técnicas, Buenos Aires, Argentina

<sup>6</sup>Department of Medicine, Indiana University, Indianapolis, IN, USA

## \*Correspondence

Jennifer Drummond, National Foundation for the Centers for Disease Control and Prevention, Atlanta, GA, USA.  
Email: wta6@cdc.gov

## Abstract

Appropriate collection and use of health information is critical to the planning, scaling up, and improvement of cervical cancer programs. The health information systems implementation landscape is unique to each country; however, systems serving cervical cancer programs in low-resource settings share characteristics that present common challenges. In response, many programs have taken innovative approaches to generating the quality information needed for decision making. Recent advances in health information technology also provide feasible solutions to challenges. This article draws from the experiences of the authors and from current literature to describe outstanding challenges and promising practices in the implementation of cervical cancer data systems, and to make recommendations for next steps. Recommendations include engaging all stakeholders—including providers, program managers, implementing partners, and donors—in promoting national, district, and community information systems; building on existing systems and processes, as well as introducing new technologies; and evolving data collection and data systems as programs advance.

## KEYWORDS

Cervical cancer; Data use; Health information systems; Low-resource settings; Patient and program monitoring

## 1 | INTRODUCTION

Cervical cancer screening and treatment services in low-resource settings are often provided within a complex landscape. High-quality services may be found in select locations, but service delivery outside these areas is often uncoordinated and exhibits varying degrees of standardization, oversight, and ownership by national governments. Information systems that serve these cervical cancer programs have similar challenges, with some examples of outstanding leadership and innovation in an overall environment in need of standards and coordination.

Current global guidance<sup>1-4</sup> posits that the appropriate collection and use of health information is critical to planning, scaling up, and improving cervical cancer programs. Population survey data are needed to inform the level of awareness, need for, and receipt of

services; and facility survey data help inform service availability, facility readiness, and quality of care. Costing data support planning for and evaluating start-up and scale-up of cervical cancer services. Routinely collected clinical data inform patient and program management, while evaluation and research projects help advance innovations in science and improvements in programs. Data from cancer registries and vital registration systems can inform the burden and impact of cervical cancer in populations.

In 2013 the Bill & Melinda Gates Foundation funded a project, Improving Data for Decision-Making in Global Cervical Cancer Programmes (IDCCP), to foster better understanding of the cervical cancer service and data situation in low-resource settings; conduct assessments of cervical cancer data systems in five low-resource countries; coordinate the development of standardized tools for collection and

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2017 The Authors. *International Journal of Gynecology & Obstetrics* published by John Wiley & Sons Ltd on behalf of International Federation of Gynecology and Obstetrics



use of cervical cancer data derived from population-based household surveys, facility surveys, costing assessments, and patient and program monitoring; and identify priorities for future investment. The program is a partnership of the CDC Foundation, the Centers for Disease Control and Prevention (CDC), the George W. Bush Institute (Bush Institute), and the WHO, and will publish a complete toolkit in 2017. The present article draws on information from this project, current literature, and the experiences of the authors to describe outstanding challenges and recent advances in implementing cervical cancer data systems, and to offer practical recommendations for next steps.

## 2 | CHARACTERISTICS OF CERVICAL CANCER DATA SYSTEMS

Across countries assessed in the IDCCP project, and others described in current literature, several characteristics common to systems providing cervical cancer care in low- and middle-income countries (LMICs) emerge. Most importantly, national cervical cancer programs are frequently underfunded, lacking program-specific budgets to ensure adequate human and material resources.<sup>5-7</sup> In this situation, it is difficult to justify allocating funds for collecting information and monitoring programs over delivering clinical services.<sup>8</sup> As a result, many cervical cancer programs do not have funds dedicated to data and data systems, and monitoring and evaluation funds either do not exist or are well below the recommended 10% of total budget.<sup>9</sup>

Cervical cancer programs often rely wholly on existing national or organizational health information systems (HIS) to serve their data needs. Where systems are unable to provide the basic information necessary to manage patients and monitor service delivery, many programs develop ad hoc systems. Even with national level policies and plans in place, cervical cancer data practices are often uncoordinated and lack standardization, which results in inconsistent data quality and availability and limits the use of data for decision making and program planning.

National cervical cancer prevention and control activities typically fall under one or more different directorates or units, including non-communicable diseases and cancer; sexual and reproductive health; infectious diseases and HIV; and immunization. Therefore, cervical cancer data needs tend to be driven initially by the reporting requirements of these points of entry or integration for cervical cancer service delivery.

## 3 | COMMON CHALLENGES

Cervical cancer services in LMICs tend to be spread across health system levels of care, with a need for clinical data to flow among them (Fig. 1). Data must also flow out of the entities at each level for program monitoring, management of supplies, and registration of providers and services. In addition to routine clinical service delivery data and facility data (e.g. staffing, equipment, and supplies) sourced from the different levels, information from population-based and facility-based surveys,

research studies, and evaluations can supplement the evidence base for programming. While each country system has unique features, the shared context of service delivery, information needs, and data systems characteristics creates common challenges in LMICs.

### 3.1 | Limitations of existing health information systems and information and communication technology infrastructure

Cervical cancer program monitoring requires totals or counts (i.e. aggregate data) that summarize the delivery and outcomes of services provided to individual women. Summary data from each facility and laboratory are further aggregated to create datasets for district, regional, and national level monitoring. The ability to exchange information among the systems that collect and manage health data (HIS) is fundamental to quality data aggregation<sup>10,11</sup>; however, in most low-resource settings, systems are fragmented and lack this necessary interoperability.<sup>12,13</sup> Information exchange and data aggregation are further limited by the absence of national unique personal identifiers. Manual aggregation processes in paper-based information systems present an additional obstacle to ensuring the quality and timeliness of data for decision making.

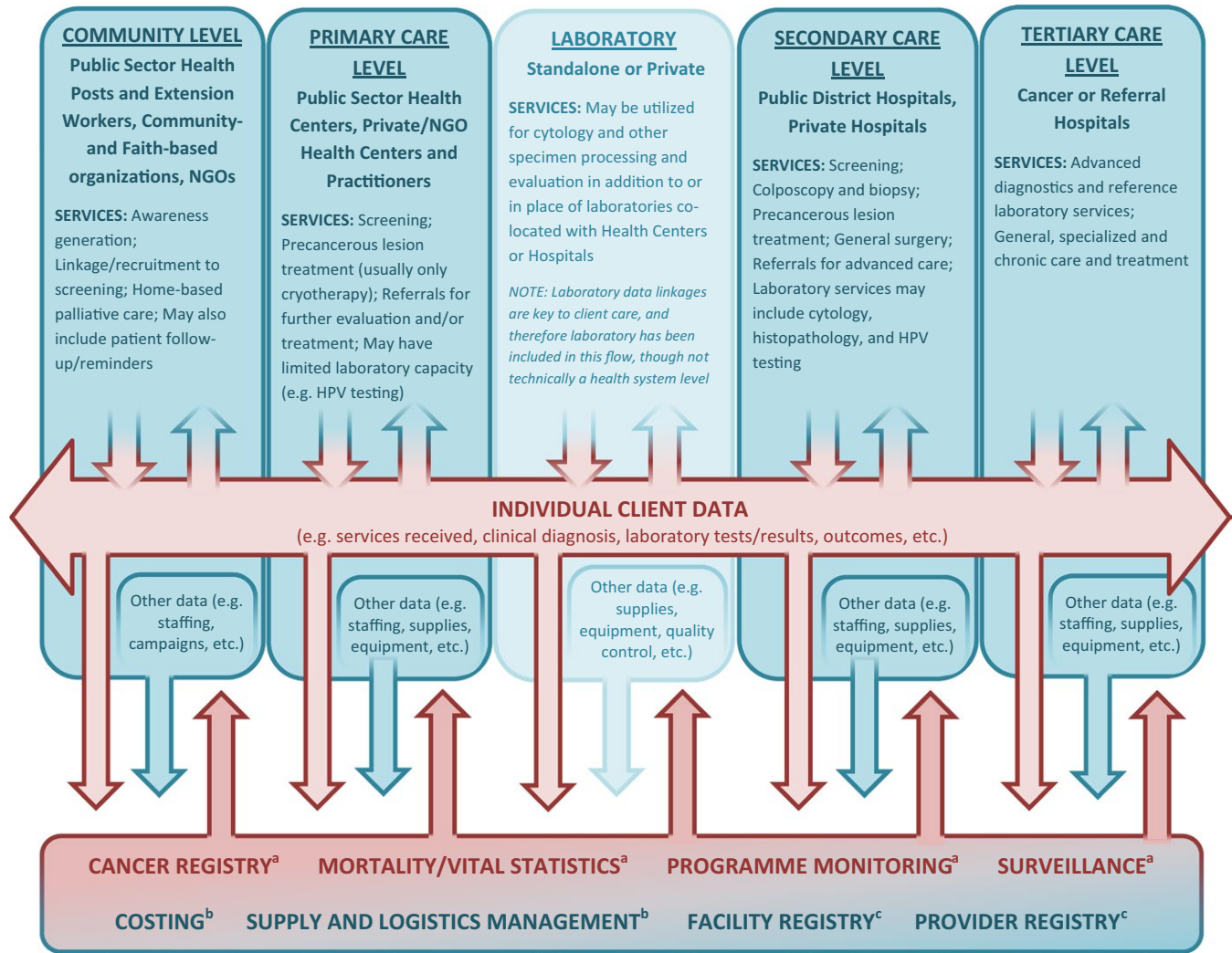
National eHealth and information and communication technology (ICT) policies do not exist in many low-resource settings<sup>13</sup>; when in place, implementation is often piecemeal owing to challenges in “retrofitting” a coherent architecture that allows information exchange among existing systems. Insufficient connectivity, hardware, and staff training often lead to a lack of adoption of nationally endorsed patient-level electronic record systems or aggregate systems.<sup>8,14</sup> Inadequate funding for system maintenance, a limited local ICT workforce, and proprietary software restrictions present challenges for improving existing systems. In response, programs may develop additional stand-alone, often parallel, processes to satisfy data needs.

### 3.2 | Relative importance of cervical cancer information

Cervical cancer programs often receive an inadequate share of national health funding,<sup>6,15</sup> leading to a lack of capacity to establish and coordinate standardized data processes across service providers. The absence of standardized terminology, minimum datasets, and data collection tools further contributes to a poor understanding of disease burden and service delivery.<sup>6,7</sup> This weak evidence base inhibits the ability of stakeholders to advocate for political commitment and resources.

### 3.3 | Complexity of the client pathway: Linking data from screening through to outcomes

Patient monitoring requires provider access to key information from each point of patient interaction with the health system. Many women seeking cervical cancer services attend multiple visits, often at different facilities. While women may not directly access laboratory



**FIGURE 1** Levels of care: Cervical cancer services and data flow. <sup>a</sup>These data are typically aggregate data with capacity for some level of disaggregation. Exceptions include reporting of individual client mortality events into Civil Registration and Vital Statistics Systems (CRVSS), and individual facility/laboratory and provider data reported for surveillance and quality monitoring. <sup>b</sup>Informed by facility data (e.g. supply inventory, line item costs) and analysis of client data and trends in service delivery (e.g. number of women who access/are expected to access screening services, number of women expected to require treatment). <sup>c</sup>Not informed by client data. Source: Content related to services provided at different levels of care was adapted from WHO.<sup>1</sup> [Colour figure can be viewed at wileyonlinelibrary.com]

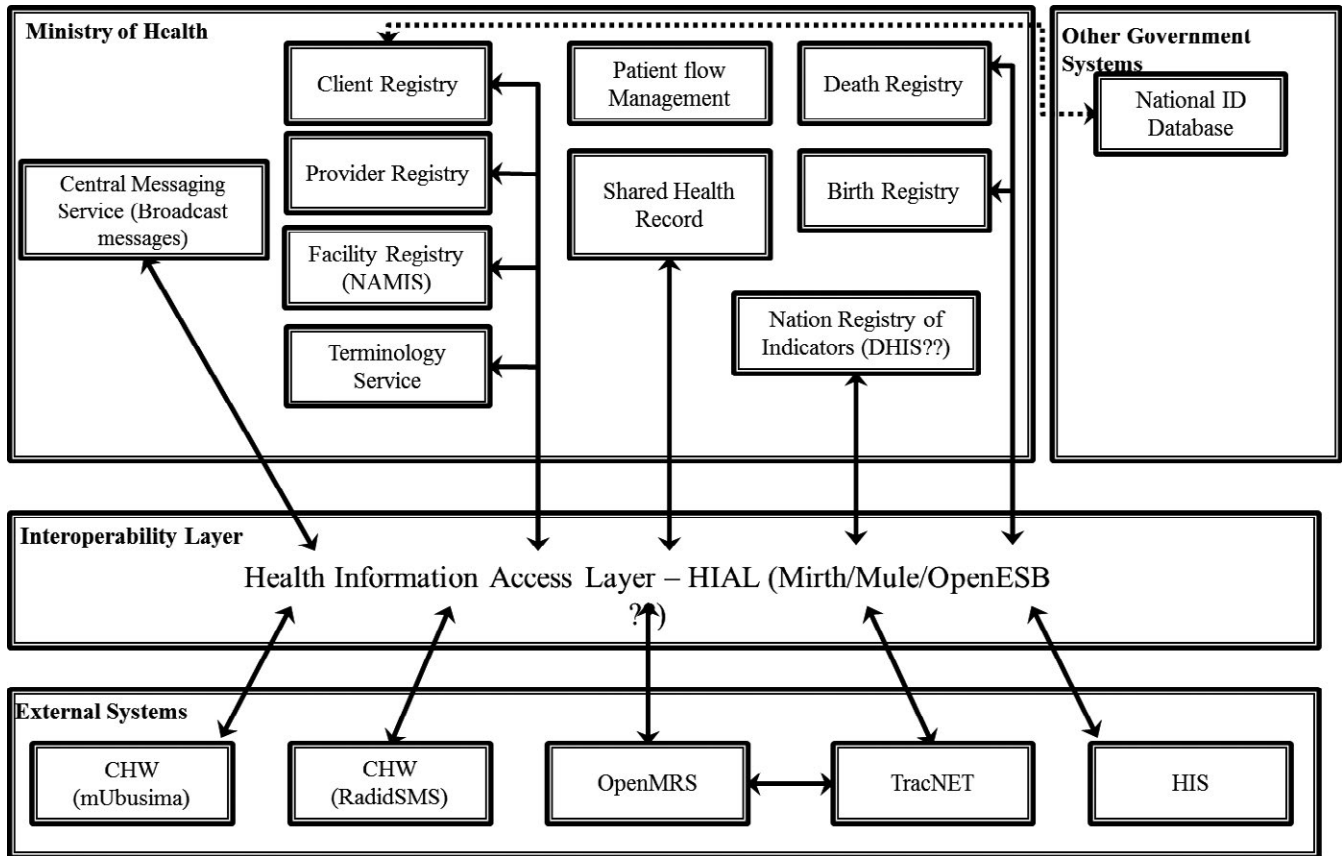
(e.g. cytology, HPV testing, biopsy) or pharmacy services, these data are also vital to patient management. Gaps in the exchange of standardized health information have immediate implications for quality of patient care. Poor referral feedback mechanisms and the absence of unique patient identifiers significantly reduce provider ability to determine treatment compliance and effectiveness. Ensuring adequate patient follow-up thus requires more active efforts, such as phone calls or physical follow-up, further adding to the burden on resources.

Data on patient outcomes are also important for estimating program impact and effectiveness. Many LMICs have used facility- or population-based cancer registries and vital registration systems to understand the burden of disease in populations; however, poor quality and limited scope frequently render this outcomes data insufficient for assessing how well programs are doing.<sup>7,16,17</sup> The

inability of existing systems to consistently link data on a patient's outcomes to the services she received translates to inaccurate aggregate data and difficulties in calculating indicators (e.g. treatment rate), thus limiting ability to monitor programs and understand their effectiveness.<sup>7</sup>

### 3.4 | Inconsistent use of routine data for planning and management

The inconsistent use of cervical cancer data can be viewed as both a result of and a contributing factor to the aforementioned challenges. Limited coordination, training, and standardization of data practices result in low-quality data. Conversely, failure to recognize the benefits of data use contributes to a lack of investment in the collection of high-quality data.<sup>8,18,19</sup>



**FIGURE 2** Illustration of the Rwanda Health Exchange Architecture (RHEA).<sup>28</sup> Created by JE Shivers, reproduced under CC BY 4.0, available at: <https://wiki.ohie.org/pages/viewpage.action?pageId=10486056>. Accessed April 20, 2017.

## 4 | RECENT ADVANCES AND PROMISING PRACTICES

Despite ongoing challenges, many cervical cancer programs have improved service delivery by taking innovative approaches to gathering information. Observations in the field supplemented by nonsystematic review of current literature support the descriptions offered here of several feasible solutions.

### 4.1 | Advances in health information technology

As health information technology solutions for low-resource settings continue to advance, opportunities for cervical cancer programs to build on and leverage existing national systems will expand. Customizable electronic platforms, such as the Open Medical Record System (OpenMRS) for managing patient data, and the District Health Information Software 2 (DHIS 2) for managing, analyzing, and visualizing aggregate program data, are being implemented in a number of countries for priority health areas (e.g. HIV/AIDS, maternal and child health). Designed with the information technology challenges in LMICs in mind, OpenMRS was originally developed in 2004 through a collaboration between Partners in Health, the Regenstrief Institute, and later the South African Medical Research Council<sup>20</sup>; and DHIS2

was developed under the leadership of the Health Information Systems Programme (HISP) at University of Oslo and first implemented in 2006, continuing the participatory approach to iterative development of earlier versions of the DHIS application which began in 1997.<sup>21</sup> Both systems continue to benefit from the collaborative approach through ongoing development by global communities of practice and support. These solutions have built-in flexibility that enables incorporation of functionalities, data elements, and indicators for other programs,<sup>20–22</sup> including cervical cancer.<sup>23</sup> The capacity for automation of indicator data reporting from the patient level (OpenMRS) to the subnational and national levels (DHIS 2) reduces burden and enhances the quality and timely availability of data for monitoring, as seen in HIV/AIDS and other programs.<sup>24,25</sup> Where disparate existing platforms present a barrier, freely available standards-based approaches to “retrofitting” information exchange in existing electronic HIS can help countries with limited resources<sup>11,26</sup>—as exemplified in the implementation of national HISs in Sierra Leone and Rwanda among others.<sup>11,25–27</sup> Illustrated in Figure 2, the Rwanda Health Exchange Architecture (RHEA) is a reference implementation of the Open Health Information Exchange (OpenHIE) community of practice,<sup>11,26</sup> which uses health information mediator middleware and a shared health record adapter module to enable exchange and querying of data from several components—including the OpenMRS-based



point-of-care medical record, and the RapidSMS mobile data collection tool originally developed by UNICEF's Innovation Unit in 2007.<sup>11,27,28</sup>

An alternative to open source models, the adaptable SmartCare electronic health record program (developed by the Centers for Disease Control and Prevention and the government of Zambia, launched in 2006<sup>13</sup>) addresses the common challenge of gaps in connectivity through offline data entry and "portable data." This method enables maintenance of a longitudinal health record (i.e. across time and continuum of care) through a PIN-protected patient card, which stores synced health visit data.<sup>13,29</sup> Processes such as probabilistic record linkage have also been successful in linking cervical cancer data across disparate systems to create ad hoc longitudinal patient records.<sup>30</sup> These models can be evaluated to determine feasibility for local implementation,<sup>14</sup> and capacity to serve cervical cancer data needs.<sup>23</sup>

Understanding local resources, information needs, and existing systems can lead to development of evidence-based systems and successful use of new information technologies.<sup>12,31–33</sup> Where an adaptable national health management information system exists, cervical cancer information needs can be satisfied through modular incorporation of minimum datasets, as in the case of the SIGSA system in Guatemala. If existing systems cannot be expanded, systems incorporating technological advances may be introduced, as with the system developed by the National Program on Cervical Cancer Prevention in Argentina.<sup>34</sup> An investigation of the program revealed an absence of registries for cervical cancer event data and lack of personnel or budget for developing an information system.<sup>35</sup> This guided the design and implementation of SITAM, an online system accessible to program managers and health services that records data for cervical cancer screening, diagnostic, and treatment procedures in the public health system. The system and its technical support and maintenance staff are funded by the national Ministry of Health. At present, 21 of 24 provinces in Argentina use SITAM, with data available for more than 1.5 million women screened in public institutions. Data are used to monitor annual screening goals and quality of screening tests, as well as to identify women who are not in compliance with follow-up and treatment procedures. SITAM also has been expanded to include registration of events related to breast and colon cancer. The evidence-based local development of SITAM and similar systems, such as the SIVIPCAN surveillance system in Nicaragua, provide opportunities for other countries in the region to learn from these experiences.

## 4.2 | Smart use of mobile and other technologies

Establishing reliable internet connectivity nationally is often a long-term goal in low-resource settings; however, mobile networks may provide a more immediate solution to ensuring rapid availability of quality health data. Mobile health (mHealth) technologies were regularly the subject of discussion across countries and experts during IDCCP project implementation, and have been the focus of a number of recent reviews and inventories.<sup>34,36–39</sup> Limited-scale implementation of applications—for data collection, clinical decision support, and follow-up visit reminder systems—has provided valuable information

regarding feasibility, usability, acceptability, and ability to promote quality data collection. Common lessons learned are the need to understand local conditions in-depth prior to implementation, continually evaluate systems to ensure they meet user needs, and provide periodic supervision to enhance data quality and use.<sup>19,40,41</sup>

In Zambia, a system for telemedicine and quality assurance that combines mobile telecommunications and digital cervicography played a vital role in improving and scaling up visual inspection with acetic acid (VIA)-based cervical cancer screening.<sup>42,43</sup> A similar approach using smartphones to capture and transmit digital cervical images has been successfully tested in Madagascar,<sup>44</sup> and scaled-up in Botswana.<sup>45,46</sup> Taking mobile digital image capture a step further, an enhanced visual assessment (EVA) system tested in Kenya combines a smartphone-integrated colposcope with a decision-support job aid that records data on VIA test results, treatment decisions, and follow-up/rescreen dates. The embedded mobile portal allows upload and real-time data aggregation and monitoring and evaluation.<sup>47</sup> In other applications, data exchange over mobile networks has been facilitated by cloud-based data storage,<sup>48</sup> multimedia messaging service or MMS,<sup>44</sup> and electronic medical pathways.<sup>11,49</sup> While mHealth technologies offer promising solutions for low-resource settings, additional evidence on scalability and impact on health outcomes is needed.<sup>19,36</sup>

## 4.3 | Strategies for improving cervical cancer data quality and use

A number of partnership initiatives are seeking to advance the culture of data use through cooperation, coordination, and innovative uses of existing program resources. For example, Pink Ribbon Red Ribbon (PRRR) aims to harmonize reporting requirements with country priorities through support to countries for adapting and implementing data standards. This mutually beneficial approach strengthens the quality of the data reported to the donor (PRRR) and increases availability of quality data for country decision making. In Latin America, the working group on cervical cancer prevention from the Network of National Cancer Institutions from the Union of South American Countries (RINC-UNASUR) has identified the development of information systems as one of the nine priority areas for action by governments,<sup>50</sup> with the network playing an essential role in technical guidance and the sharing of knowledge.

Field observations during the IDCCP project suggested that expanding the portion of the health workforce that understands the important role of cervical cancer data is another way to promote data quality and use. An example is Jhpiego's multifaceted approach in countries where DHIS 2 is in use: access is enhanced through integration of cervical cancer indicators and data dashboards showing trends. Jhpiego also utilizes "Results at a Glance" posters, a tool for tracking key indicators for provider level data use,<sup>2</sup> and has integrated and expanded the building of monitoring and evaluation skills within a standard package of clinical service provider training.<sup>51</sup>

While not specific to cervical cancer, a number of publications explore improvements in data quality and provider use through integration of data skills into clinical trainings<sup>52,53</sup> or specific workshops





and trainings on the importance of data use.<sup>18,54,55</sup> Leveraging the valuable position of community health workers, many countries have provided training on data collection and use; this both fosters appreciation for data collection tasks and enables active improvement of data quality (e.g. obtaining missing data, following up with patients after referral to determine outcomes, and validating vital registration system data).<sup>41,52,56–60</sup> A common lesson across interventions is the need to supplement training with supportive supervision, feedback mechanisms, and reliable, timely access to data.

## 5 | RECOMMENDATIONS

Common challenges and lessons learned through the evolution of existing practices, with added perspective gained from IDCCP project implementation, provide the basis for recommendations for next steps in strengthening cervical cancer data systems, as described here.

### 5.1 | Prioritize needs for data and data systems

Thinking in practical terms about data needs and focusing on what is essential for both patient care and program improvement should steer plans for data systems. Data collectors and users can be engaged in the process of adopting a nationally standardized minimum dataset and set of indicators. The basic questions that guide implementation of national, district, and community monitoring and evaluation and information systems more generally<sup>10,31</sup> can also help when designing responses to the needs for cervical cancer data. Guidance documents such as the WHO Comprehensive Cervical Cancer Control: Guide to Essential Practice,<sup>1</sup> the PAHO Manual for Integrating HPV Testing in Cervical Cancer Programs,<sup>3</sup> and the ACCP Planning and Implementing Cervical Cancer Prevention and Control Programs,<sup>4</sup> outline basic information needs for cervical cancer program start-up, scale-up, and improvement. Tools such as those developed by the IDCCP project can support operationalization within country contexts.

### 5.2 | Engage national stakeholders around data

The term “stakeholders” can be applied broadly to include all those in the public and private sector who truly have a “stake” in cervical cancer data: service providers, implementing partners, program managers, monitoring and evaluation and surveillance personnel, eHealth and IT personnel, representatives from integrated programs, and donors. The goal is to increase ownership of the data collected, by showing how the data are harnessed to improve programs. A stakeholder approach not only fosters appreciation for data use, but also promotes adoption of systems. The integration of training for data collection, data use, and monitoring and evaluation into clinical skills training for service providers further solidifies the understanding of how collecting high quality data can improve the quality of care and save lives. A clear, widely disseminated national policy on reporting processes and timelines, coupled with activities that enhance the

culture of data use, provides structure and support for timely availability of data.

### 5.3 | Integrate with, and build on, existing systems and processes

Beginning steps for strengthening information systems should include assessing local system landscapes, ICT infrastructure, and user needs to identify solutions that promote a coherent health information systems architecture. Harmonizing existing cervical cancer indicators and monitoring systems allows system strengthening to be informed by practical experiences. Leveraging program integration to achieve incorporation of minimum datasets into existing electronic patient health records and aggregate data systems or established paper-based systems can optimize limited resources.

An alternative to investing in new electronic systems and processes is to fully explore existing system functions (e.g. automated data quality checks, access management, and options for data visualization) and consider recent advances in open-source software or mobile technology to increase flexibility and interoperability. New systems should have capacity for information exchange and be adaptable to changing local needs. Whatever approach program needs dictate, it is vital to ensure accurate costing, to allocate resources for system development, implementation, maintenance, and to build capacity for local support.

### 5.4 | Evolve data collection and data systems as needed

Important lessons can be learned from information systems in similar country conditions, and from the evolution of monitoring and evaluation and surveillance systems in other disease areas, such as HIV. A clear vision for short-, medium-, and long-term progress and data needs is key to laying the foundation of systems that can evolve as programs advance.<sup>20,21,25,27,61,62</sup> Advancement and innovative use of technologies provide exciting opportunities for piloting and implementing in research settings or Centers of Excellence<sup>23</sup>—but a focus on simplicity should be maintained, with incremental implementation of what is practical, feasible, affordable, and necessary for the country and the program.

## 6 | CONCLUSION

Many of the ongoing challenges to implementing robust data systems for cervical cancer are rooted in national health system challenges; however, innovative technologies and promising practices provide ways to strengthen these systems. The most encouraging, sustainable options observed over the 3-year IDCCP project either leveraged existing systems (for HIV or general health) or provided a fairly immediate benefit to the broader health information system or health system landscape. These “broader impact” practices included: cervical cancer program adoption of a standardized minimum dataset, data collection tools, and monitoring mechanisms, and the use of these coordinated



practices to “benchmark” monitoring and evaluation for other national programs; enhanced understanding of the value of quality health data in general, through integration of data skills into cervical cancer training for providers and community health personnel; and cervical cancer program testing of mHealth technologies (telemedicine, follow-up reminder systems) and locally adapted standardized tools for quality assurance, to inform broader national health strategies and pilot programs. When exploring strategies for strengthening data systems and advocating for resources, cervical cancer programs are in a position not only to leverage related health areas, but also to market the broader health system impact of these improvements.

## AUTHOR CONTRIBUTIONS

JD conducted literature searches, drafted and revised the manuscript. SA, MW, and KWK conducted literature searches and drafted key content. All authors were responsible for reviewing and approving the final manuscript.

## ACKNOWLEDGMENTS

The authors would like to thank Dr Laura Porter of the U.S. Centers for Disease Control and Prevention, Alyssa Lowe of the CDC Foundation, Megan Wysong of Jhpiego, and Dr Adetoun Olateju of Pink Ribbon Red Ribbon for their valuable contributions to this manuscript. The views expressed by the authors reflect the opinions of the authors, and not necessarily those of the institutions with which they were affiliated during the time the work was conducted (CDC Foundation, the IDCCP project consortium, IDCCP project grant donor, etc.).

## CONFLICTS OF INTEREST

The authors do not report any conflicts of interest.

## REFERENCES

- World Health Organization. *Comprehensive Cervical Cancer Control: A Guide to Essential Practice*, 2nd edn. Geneva: WHO; 2014.
- World Health Organization. *Monitoring National Cervical Cancer Prevention and Control Programmes: Quality Control and Quality Assurance for Visual Inspection With Acetic Acid (VIA)-Based Programmes*. Geneva: WHO; 2013.
- Organization P. *Integrating HPV Testing in Cervical Cancer Screening Program: A Manual for Program Managers*. Washington, DC: PAHO; 2016.
- Alliance for Cervical Cancer Prevention. *Planning and Implementing Cervical Cancer Prevention and Control Programs: A Manual for Managers*. Seattle: ACCP; 2004.
- Ginsburg O, Bray F, Coleman MP, et al. The global burden of women's cancers: a grand challenge in global health. *Lancet*. 2017;389:847–860.
- Elit L, Jimenez W, McAlpine J, Ghatage P, Miller D, Plante M. Cervical cancer prevention in low-resource settings. *J Obstet Gynaecol Can*. 2011;33:272–279.
- Organization P. *Cervical Cancer Prevention and Control Programs: A Rapid Assessment in 12 Countries in Latin America*. Washington, DC: PAHO; 2010.
- Moucheraud C, Schwitters A, Boudreaux C, et al. Sustainability of health information systems: a three-country qualitative study in southern Africa. *BMC Health Serv Res*. 2017;17:23.
- World Health Organization. *Health Promotion Evaluation: Recommendations to Policy-Makers*. Geneva: WHO; 1998.
- Health Metrics Network. *Framework and Standards for Country Health Information Systems*, 2nd edn. Geneva: WHO; 2008.
- OpenHIE. Open Health Information Exchange community of practice. <http://ohie.org/>. Accessed February 18, 2017.
- Mudaly T, Moodley D, Pillay A, Seebregts CJ. Architectural frameworks for developing national health information systems in low and middle income countries. *Proc IEEE Enterprise Systems Conference* 2013:1–9.
- Vital Wave Consulting. *Health Information Systems in Developing Countries: A Landscape Analysis*. Palo Alto: Vital Wave; 2009.
- Tilahun B, Fritz F. Comprehensive evaluation of electronic medical record system use and user satisfaction at five low-resource setting hospitals in Ethiopia. *JMIR Med Inform*. 2015;3:e22.
- Denny L, de Sanjose S, Mutebi M, et al. Interventions to close the divide for women with breast and cervical cancer between low-income and middle-income countries and high-income countries. *Lancet*. 2017;389:861–870.
- Stefan DC, Elzawawy AM, Khaled HM, et al. Developing cancer control plans in Africa: examples from five countries. *Lancet Oncol*. 2013;14:e189–e195.
- Lopez AD, Setel PW. Better health intelligence: a new era for civil registration and vital statistics. *BMC Med*. 2015;13:73.
- Ledikwe JH, Grignon J, Lebelonyane R, et al. Improving the quality of health information: a qualitative assessment of data management and reporting systems in Botswana. *Health Res Policy Syst*. 2014;12:7.
- Rajan JV, Moura J, Gourley G, et al. Understanding the barriers to successful adoption and use of a mobile health information system in a community health center in São Paulo, Brazil: a cohort study. *BMC Med Inform Decis Mak*. 2016;16:146.
- Mamlin B, Biondich PG, Wolfe BA, et al. Cooking up an open source EMR for developing countries: OpenMRS – A recipe for successful collaboration. *AMIA Annu Symp Proc*. 2006;2006:529–533.
- University of Oslo Health Information Systems Programme. The process of developing the DHIS. <https://www.mn.uio.no/ifi/english/research/networks/hisp/hisp-history.html>. Accessed April 20, 2017.
- Allen C, Jazayeri D, Miranda J, et al. Experience in implementing the OpenMRS medical record system to support HIV treatment in Rwanda. In: Kuhn KA, Warren JR, Leong T-Y, eds. *MEDINFO 2007*. Amsterdam: IOS Press; 2007:382–386.
- Tapela NM, Mpunga T, Hedt-Gauthier B, et al. Pursuing equity in cancer care: implementation, challenges and preliminary findings of a public cancer referral center in rural Rwanda. *BMC Cancer*. 2016;16:237.
- Kariuki JM, Manders E-J, Richards J, et al. Automating indicator data reporting from health facility EMR to a national aggregate data system in Kenya: an Interoperability field-test using OpenMRS and DHIS2. *Online J Public Health Inform*. 2016;7:e188.
- Braa J, Kanter AS, Lesh N, et al. Comprehensive yet scalable health information systems for low resource settings: a collaborative effort in Sierra Leone. *AMIA Annu Symp Proc*. 2010;2010:372–376.
- OpenHIM. Open Health Information Mediator middleware to enhance interoperability. <http://openhim.org/>. Accessed February 18, 2017.
- Crichton R, Moodley D, Pillay A, Gakuba R, Seebregts CJ. An architecture and reference implementation of an open health information mediator: enabling interoperability in the Rwandan health information exchange. In: Weber J, ed. *FHIES 2012, LNCS 7789*. Berlin Heidelberg: Springer-Verlag; 2013:87–104.



28. Rapid SMS. Rapid SMS mobile data collection application. <https://www.rapidsms.org/about/>. Accessed April 20, 2017.
29. Mweebo K. Security of electronic health records in a resource limited setting: The case of smart-care electronic health record in Zambia. Proceedings of 3rd Australian eHealth Informatics and Security Conference, 1-3 December 2014, Perth, Western Australia.
30. Freire SM, Terezinha de Almeida R, BorgesCabral MD, de Assis Bastos E, Cristovão Souza R, Pereira de Silva MG. A record linkage process of a cervical cancer screening database. *Comput Methods Programs Biomed.* 2012;108:90-101.
31. World Health Organization; PATH. *Planning an Information Systems Project: A Toolkit for Public Health Managers.* Seattle: PATH; 2013.
32. Fritz F, Tilahun B, Dugas M. Success criteria for electronic medical record implementations in low-resource settings: a systematic review. *J Am Med Inform Assoc.* 2015;22:479-488.
33. Mair FS, May C, O'Donnell C, Finch T, Sullivan F, Murray E. Factors that promote or inhibit the implementation of e-health systems: an explanatory systematic review. *Bull World Health Organ.* 2012;90:357-364.
34. World Health Organization. *Compendium of Innovative Health Technologies for Low-Resource Settings. Assistive Devices. eHealth Solutions. Medical Devices.* Geneva: WHO; 2013.
35. Arrossi S, Paolino M, Sankaranarayanan R. Challenges faced by cervical cancer prevention programs in developing countries: a situational analysis of program organization in Argentina. *Rev Panam Salud Publica.* 2010;28:249-257.
36. Davis SW, Oakley-Girvan I. mHealth applications along the cancer continuum. *J Cancer Educ.* 2015;30:388-394.
37. Källander K, Tibenderana JK, Akpogheneta OJ, et al. Mobile Health (mHealth) Approaches and lessons for increased performance and retention of community health workers in low-and middle-income countries: a review. *J Med Internet Res.* 2013;15:e17.
38. Labrique AB, Vasudevan L, Kochi E, Fabricant R, Mehl G. mHealth innovations as health systems strengthening tools: 12 common applications and a visual framework. *Glob Health Sci Pract.* 2013;1:160-171.
39. Batavia H, Kaonga N. *mHealth Support Tools for Improving the Performance of Frontline Health Workers: An Inventory and Analytical Review.* Washington, DC: mHealth Alliance; 2013.
40. Rothstein JD, Jennings L, Moorthy A, et al. Qualitative assessment of the feasibility, usability, and acceptability of a mobile client data app for community-based maternal, neonatal, and child care in rural Ghana. *Int J Telemed Appl.* 2016;2016:2515420.
41. Joos O, Silva R, Amouzou A, et al. Evaluation of a mHealth data quality intervention to improve documentation of pregnancy outcomes by health surveillance assistants in Malawi: a cluster randomized trial. *PLoS ONE.* 2016;11:e0145238.
42. Mwanahamuntu MH, Sahasrabudde VV, Blevins M, et al. Utilization of cervical cancer screening services and trends in screening positivity rates in a 'screen-and-treat' program integrated with HIV/AIDS care in Zambia. *PLoS ONE.* 2013;8:e74607.
43. Parham GP, Mwanahamuntu MH, Pfaendler KS, et al. eC3 - a modern telecommunications matrix for cervical cancer prevention in Zambia. *J Low Genit Tract Dis.* 2010;14:167-173.
44. Catarino R, Vassilakos P, Scaringella S, et al. Smartphone use for cervical cancer screening in low-resource countries: a pilot study conducted in Madagascar. *PLoS ONE.* 2015;10:e0134309.
45. Quinley KE, Gormley RH, Ratcliffe SJ, et al. Use of mobile telemedicine for cervical cancer screening. *J Telemed Telecare.* 2011;17:203-209.
46. Ndlovu K, Littman-Quinn R, Park E, Dikai Z, Kovarik CL. Scaling up a mobile telemedicine solution in Botswana: keys to sustainability. *Front Pub Health.* 2014;2:275.
47. Peterson CW, Rose D, Mink J, Levitz D. Real-time monitoring and evaluation of a visual-based cervical cancer screening program using a decision support job aid. *Diagnostics (Basel).* 2016;6(2). pii: E20.
48. Haskew J, Ro G, Turner K, Kimanga D, Sirengo M, Sharif S. Implementation of a cloud-based electronic medical record to reduce gaps in the HIV treatment continuum in rural Kenya. *PLoS ONE.* 2015;10:e0135361.
49. Vista Life Sciences. Vista Life Sciences electronic medical pathways. <http://vitalifesciences.com/emp-introduction>. Accessed February 18, 2017.
50. Red de Institutos Nacionales de Cáncer. El grupo operativo de prevención de cáncer cervicouterino. Rio de Janeiro: RINC; 2016. RINC-UNASUR. [http://www2.rinc-unasur.org/wps/wcm/connect/RINC/site/home/grupos\\_operativos/control\\_cancer\\_cuello\\_uterino](http://www2.rinc-unasur.org/wps/wcm/connect/RINC/site/home/grupos_operativos/control_cancer_cuello_uterino). Accessed December 12, 2016.
51. Anderson J, Wysong M, Estep D, et al. Evaluation of cervical cancer screening programs in Côte d'Ivoire, Guyana, and Tanzania: effect of HIV status. *PLoS ONE.* 2015;10:e0139242.
52. Drobac PC, Basinga P, Condo J, et al. Comprehensive and integrated district health systems strengthening: the Rwanda Population Health Implementation and Training (PHIT) partnership. *BMC Health Serv Res.* 2013;13(Suppl2):S5.
53. Hirschorn LR, Baynes C, Sherr K, et al. Approaches to ensuring and improving quality in the context of health system strengthening: a cross-site analysis of the five African Health Initiative Partnership programs. *BMC Health Serv Res.* 2013;13(Suppl2):S8.
54. Braa J, Heywood A, Sahay S. Improving quality and use of data through data-use workshops: Zanzibar, United Republic of Tanzania. *Bull World Health Organ.* 2012;90:379-384.
55. Mphatswe W, Mate KS, Bennett B, et al. Improving public health information: a data quality intervention in KwaZulu-Natal, South Africa. *Bull World Health Organ.* 2012;90:176-182.
56. Admon AJ, Bazile J, Makungwa H, et al. Assessing and improving data quality from community health workers: a successful intervention in Neno, Malawi. *Public Health Action.* 2013;3:56-59.
57. Jeremie N, Kaseje D, Olayo R, Akinyi C. Utilization of community-based health information systems in decision making and health action in Nyalenda, Kisumu county, Kenya. *Univers J Med Sci.* 2014;2:37-42.
58. Kumakech E, Andersson S, Wabinga H, Berggren V. Integration of HIV and cervical cancer screening perceptions and preferences of communities in Uganda. *BMC Womens Health.* 2015;15:23.
59. Republic of Uganda Ministry of Health. Health Sector Strategic Plan III 2010- 2015. [http://www.health.go.ug/docs/HSSP\\_III\\_2010.pdf](http://www.health.go.ug/docs/HSSP_III_2010.pdf). Accessed April 6, 2017.
60. Shagake SS, Mengistu MY, Zeleke AA. Data management knowledge, practice and associated factors of Ethiopian health extension workers in Gamo Gofa zone, southern Ethiopia: a cross-sectional study. *J Health Med Informat.* 2014;5:150.
61. Marrett LD, Robles S, Ashbury FD, Green B, Goel V, Luciani S. A proposal for cervical screening information systems in developing countries. *Int J Cancer.* 2002;102:293-299.
62. Porter LE, Bouey PD, Curtis S, et al. Beyond Indicators: advances in global HIV monitoring and evaluation during the PEPFAR era. *J Acquir Immune Defic Syndr.* 2012;60(Suppl3):S120-S126.