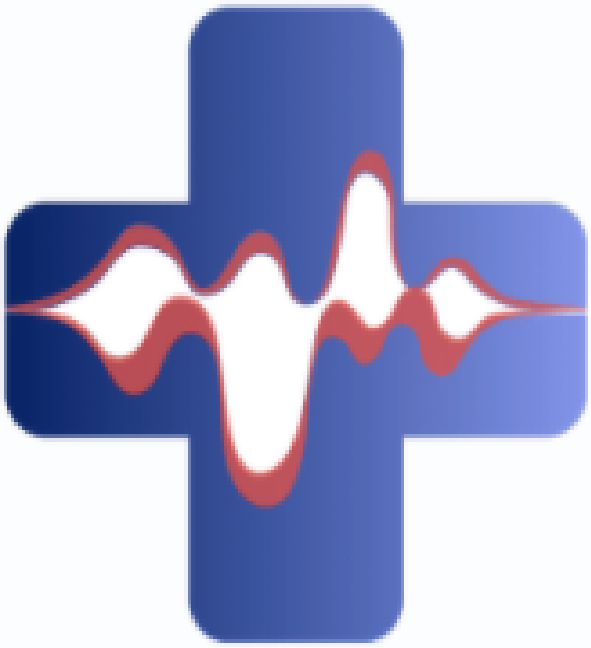

DUKE UNIVERSITY 2ND ANNUAL HEALTH POLICY CASE COMPETITION

Emerging Technology for Cervical Cancer Screening

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Introduction

According to the World Health Organization (WHO), cervical cancer is the fourth most common cancer in women. In 2018, it was estimated that 570,000 women were diagnosed with cervical cancer and 311,000 women died from this disease. Most cervical cancer occurrences are sourced from high-risk human papillomavirus (HPV) infection, commonly transmitted through sexual contact and lack of HPV vaccination. Perhaps the most encouraging fact is that if detected early, cervical cancer is one of the most successfully treatable cancers (American Cancer Society, 2020). In fact, in 2020, the WHO launched a cervical cancer elimination initiative, aiming to reach an incidence rate of four per 100,000 women by 2030.

Cervical cancer prevention can be categorized into primary, secondary, and tertiary levels (Botha, 2009). Primary preventions aim to reduce risk by preventing HPV infection. This may include HPV vaccine administration and education programs about safe sexual practices. Secondary preventions include cervical cancer screening. This has several approaches such as HPV screening, in which cervical cells are analyzed for the presence of high-risk strains of HPV that are more prone to cancer development (American Cancer Society, 2020). The Papanicolaou (Pap) smear is another method that checks for cancerous cervical cells. The American Cancer Society suggests that women over the age of 25 should receive a Pap test every three years to screen for cervical cancer regularly. Tertiary prevention and palliative care include surgery, radiotherapy, or chemotherapy. However, with proper primary and secondary prevention measures and early detection, women are 92% as likely as women who don't have cervical cancer to live for at least another five years after diagnosis (American Cancer Society, 2021). Despite this promising treatment outlook, it is projected that by the year 2030, more than 443,000 women will die from cervical cancer annually, most of whom will reside in sub-Saharan Africa* (SSA) (Mboumba Bouassa et al., 2017).

Cervical cancer in SSA is the most common cancer, as it accounts for 22% of all female cancers in SSA. The WHO estimates that about 68,000 cases of cervical cancer are detected each year in Africa. However, these numbers are most likely an underrepresentation of the actual rate of prevalence given the challenges in health information systems and cancer registries, a specific information system designed to manage and analyze cancer data across a population (World Health Organization-Regional Office for Africa, 2015). Furthermore, early cervical cancer screening and treatment is underserved, as many cases are not identified until reaching an advanced stage due to (1) insufficient access to reproductive health care services, (2) poor awareness, (3) social sigma, cultural influences, and religious beliefs that may negatively influence a woman's access and quality of care (World Health Organization-Regional Office for Africa, 2015). It is important to note that such debilitating social determinants are not individualistic but rather structural.

In the recent decade, three countries, amongst others, (1) Eswatini (previously known as Swaziland), (2) Malawi, and (3) South Africa, have experienced an increase in cervical cancer incidence rates (Jedy-Agba et al., 2020). One critical causal factor of this trend is the lack of regular and efficient cervical screening programs. Lönnberg's study demonstrates that one Pap smear in a woman's lifetime may reduce her risk of cervical cancer in the next five years after Pap smear administration by 50% (2012). Such impact is evidenced in an Australian effort to boost regular cervical screening, in which the 13.3 per 100,000 rates in 1991 was reduced to 7 per 100,000 between 2001 and 2008 (Lönnberg, 2012).Despite the successful impact of cervical cancer screening programs, many SSA countries experience competing public health priorities for funding and resource allocation as well as limited trained healthcare service providers to provide such screening services (Anaman-Torgbor et al., 2020).

Recent technologies have targeted difficulties surrounding cervical cancer screening administration. According to a 2021 American Institute of Physics report, one emerging technique features a screening tool that utilizes microbeads that form a diamond shape when in contact with HPV. These microbeads can be analyzed by microscopes, as well as a mobile phone app for greater ease in clinics with limited diagnostic instruments. For rural communities with limited technology access and physician training, this accessible technology has the potential to increase HPV screening rates and decrease cervical cancer prevalence in SSA.

*Note: We refer to sub-Saharan Africa as the geographic location associated with the 46 countries that the United Nations considers to be located in this region. We acknowledge the debate surrounding the usage of this term and would recommend researching more to understand its connotation. You can find more information here:
https://cgt.columbia.edu/news/morris-larkin-still-use-term-sub-saharan-africa/
https://qz.com/africa/770350/why-do-we-still-say-subsaharan-africa/

Case Prompt

As a domestic non-governmental agency (NGO) representative, your ideas are required to facilitate an equal 5-year partnership with your NGO and partnered SSA country. Your job is to create a strategy to successfully implement the microbead technology to increase HPV screening rates among high-risk communities in 1 of 3 SSA countries: Eswatini, Malawi, or South Africa. In particular, you should address the causes of limited HPV screening among a specific target population and indicate how to increase access. When thinking through potential resolutions, be sure to consider the socioeconomic status, cultural and religious composition, health system capacity, sustainability, and access to healthcare within the country you have selected. Solutions should include consideration of policy reforms necessary for implementation, advancement, and financial feasibility while justifying costs.

You will have 5 minutes to present your idea to a panel of judges. The presentation should be in a slide deck format (max 5 slides). You must submit your slide deck via Google Form by 11:59 am on Saturday, September 11th. You can choose to have as many people from your team present as you wish. We recommend the incorporation of data from the background, appendices, and bibliography of this document. You are also permitted to bring in data from outside sources. You will present solutions to a panel of multiple judges, including Duke faculty and members of staff at the Duke Margolis Center and FHI360. They will represent public health officials in your partnered country for the duration of this case.

Note: we will be timing you and will cut you off if your presentation runs over 5 minutes

Judging Rubric

Judges will evaluate teams based on the following rubric. They can score teams from 1 - 10, based on how teams fulfill each category, using sub-questions for guidance.

Impact (25%)

- How likely is the solution to be scaled?
- Can the team provide support for the rationale for their decisions with data/evidence?
- Are the team's resources from reliable and trustworthy sources?
- Has the team addressed capacity and operational strengths and weaknesses of their county, and tailored their proposal with these in mind?
- Did the team incorporate a quantitative measure of their proposal's impact? (i.e. use of flu shot analogy, current adoption rates, etc.)

Feasibility (25%)

- How innovative is the proposed solution?
- Has the team backed this up with wireframes/data projections/product demo? Can they explain how they arrived at these outputs?
- Has the team considered technical issues regarding their solution?
- Have they considered and explained their cost structure and revenue streams?
- Have they incorporated a strong community engagement component in the planning and implementation of the model?
- Has the team considered the longevity of their solution?

Systemic Factors (25%)

- Has the team taken into account the socioeconomic status, racial and ethnic makeup, and healthcare systems (capacity, policies, and access), structural racism, and social and political determinants of health within their chosen county when developing their response? Have they included county specific figures and statistics?
- Are there notable characteristics and resources within the team's chosen county, and have these been considered when developing a proposal?
- Has the team built on existing community, local, and state resources?
- Has the team properly defined key metrics to evaluate their proposal's viability? Can they identify their target populations?

Presentation Delivery (25%)

- How professional was the delivery?
- How well did the presentation slides support the team's delivery?
- How clear is the team when referencing the main point chosen, solution and business model?
- How persuasive was the team's pitch?

Background Information

What is Cervical Cancer?

Cervical cancer is a type of cancer that occurs in the cervix — the lower part of the uterus that connects to the vagina. Human papillomavirus (HPV), a sexually transmitted infection, is the most common cause of cervical cancer. Still, it is important to note that HPV is not the only cause of cervical cancer. Early stages of cervical cancer usually do not produce any signs or symptoms; however, once the cancer metastasizes, symptoms include vaginal bleeding during intercourse; watery, bloody vaginal discharge; and pelvic pain during intercourse (Mayo Clinic, 2021).

The main types of cervical cancer are squamous cell carcinoma and adenocarcinoma. Squamous cell carcinoma is the cancer of the thin cells that line the outer part of the cervix. Adenocarcinoma begins in the glandular cells that line the cervical canal. Squamous cell carcinoma is much more common and makes up about 90 percent of cervical carcinoma cases (Cancer Quest, 2021).

Apart from HPV, other risk factors include one's sexual history, age, smoking, a weakened immune system, chlamydia, and having multiple full-term pregnancies (American Cancer Society, 2020). In addition, very few women under 20 are diagnosed with cervical cancer. Most diagnoses are in women from 35 to 55. The risk decreases after 55, possibly due to changes in sexual behavior. Smoking can cause mutations in DNA which can lead to the suppression of the immune system which can allow HPV infections to progress into lesions or cancer. Human immunodeficiency virus (HIV) has shown a five-fold risk of developing cervical cancer due to HIV weakening the immune system and allowing HPV infections to persist. Although there is no medical link between HIV and HPV, there is a correlation due to both viruses being transmitted sexually and similar behaviors put women at risk for both viruses.

Regular Pap smear screening is important to detect abnormal cells which could indicate HPV or cervical cancer. Further tests are then performed to make a proper diagnosis. These additional tests could include a colposcopy or a biopsy. A colposcopy is a type of camera which is inserted into the vagina to observe the cervix, and a biopsy is a removal of a small tissue sample for examination. Once cancer is detected, treatment can include surgery, radiation, chemotherapy, or a combination of the above depending on the stage of the cancer (American Cancer Society, 2020).

State of Health in sub-Saharan Africa

Cervical cancer is the second most common cancer and the leading cause of cancer death in women in SSA, attributing to 21.7% of all cancer deaths in 2018 in the region (Jedy-Agba et al., 2020). Because cervical cancer can be prevented, there is an uneven distribution of incidence and mortality rates among women in SSA, especially those in Southern Africa with 80% of all new cases of cervical cancer worldwide in 2018 occuring in low- and middle-income countries (LMICs) (Jedy-Agba et al., 2020). In addition, out of the top 20 countries in the world with the highest burden of cervical cancer, 19 were located in SSA (World Cancer Research Fund, 2018). According to Jedy-Agba et al., "In contrast [to developed countries], the incidence of CC in developing countries continues to rise due to the absence of effective population-level screening programmes, poor awareness about prevention, inequitable access to health services, poverty and low socioeconomic status" (2020). Unfortunately, these challenges lead to 90% of deaths from cervical cancer. However, it should be noted that while these statistics provide generalizations across this region, they do not fully represent the state of health in individual countries, especially in a region as incredibly vast and diverse as sub-Saharan Africa, with various socioeconomic positions, cultures, and other varying factors.

The World Health Organization (WHO) estimates that cervical cancer deaths worldwide will increase to 460,000 by 2040, with the majority occurring in LMICs. On November 17, 2020, the WHO announced the Global Strategy to Accelerate the Elimination of Cervical Cancer, with a resolution passed by 194 countries. In order to eliminate cervical cancer "all countries must reach and maintain an incidence rate of below four per 100,000 women" (World Health Organization, 2020). To achieve this goal, this strategy sets three specific targets for each country to achieve by 2030:

- 90% of girls must be fully vaccinated with the HPV vaccine by the time they turn 15
- 70% of women must be screened with a high-precision test at 35 years of age, and then again at the age of 45 years
- 90% of women identified with cervical disease must receive treatment and care.

Pyramid approach to prevention (vaccination, screening, treatment)

Primary: Vaccination

The HPV vaccine can prevent most cases of cervical cancer if given before a girl or woman is exposed to the virus. Thus, the average age that most girls get vaccinated are 11 or 12, before most of them have had any sexual contact and any possible exposure to the virus. It is ideal for boys to also receive the vaccine to prevent transmission of HPV. The HPV vaccine is not recommended for pregnant women, people who are severely ill, or people who have an allergy to yeast or any other ingredient of an HPV vaccine (Mayo Clinic, 2020). The most common HPV vaccine, Gardasil, contains purified inactive proteins from HPV types 6, 11, 16, and 18 (Ogbru, 2017). These proteins resemble the HPV virus but cannot give rise to replicating the virus. The immune system is then stimulated to attack HPV types 6, 11, 16, and 18 and antibodies are developed. HPV 16 and 18 cause 70% of cervical cancer, and HPV 6, 11, 16, and 18 cause 90% of genital warts (National Cancer Institute, 2021). The use of immunosuppressive drugs reduces the near 100% efficacy of Gardasil (National Cancer Institute, 2021).

Secondary: Screening

There are two screening tests that can help prevent cervical cancer: the Pap test and the HPV DNA test. The Pap test looks for precursors to cancer which could become cervical cancer if not treated. The HPV DNA test detects the presence of HPV viral strains that can lead to the development of genital warts or cervical cancer. The HPV DNA test is recommended if the Pap test was abnormal or if the patient is 30 or older. It can take about three weeks to receive test results. If cervical cancer is suspected, a colposcopic examination is performed where the doctor takes a sample of cervical cells for laboratory testing. If the results are worrisome, the doctor may perform an electrical wire loop (usage of a thin, low-voltage wire to obtain a small tissue sample under local anesthesia) or a cone biopsy (usage of deeper layers of cervical cells for laboratory testing under general anesthesia). Once cervical cancer has been diagnosed, the extent of cancer must be determined, usually through imaging tests (CT, MRI, PET, etc.) or a visual examination of the bladder and rectum (Mayo Clinic, 2021). However, access to these treatments are varied around the world, especially in LMICs. The technological innovation you will be implementing focuses on the HPV screening exam and is a form of secondary prevention.

Tertiary: Treatment

There is no cure or treatment for HPV; however, there are medications to eliminate warts and the lesions that result from the virus. Such medications include over-the-counter salicylic acid and prescriptions such as imiquimod, podofilox, and trichloroacetic acid. Imiquimod enhances the immune system's ability to fight off HPV leading to less lesions over time while the other medications destroy genital wart tissue which may cause some irritation in the process (Mayo Clinic, 2021). There are also surgical procedures which can require the removal of the wart or

laser surgery . Electrocautery (burning with an electrical current) and cryotherapy (freezing with liquid nitrogen) are other means of removing the lesions as well (Cleveland Clinic, 2018).
With regards to cervical cancer, the most common types of treatments include surgery, radiation therapy, chemotherapy, and immunotherapy (American Cancer Society, 2020). The route taken by physicians often depends on the type and stage of the cancer. During the earlier stages, either surgery or radiation combined with chemotherapy may be used. During the later stages, radiation combined with chemotherapy is used. Chemotherapy is used by itself to treat advanced cervical cancer (American Cancer Society, 2020).

Social Determinants and Barriers to Treatment

There are four levels of barriers to treatment in screening for cervical cancer in rural SSA settings: Individual, Community, Institutional, and Policy. A majority of the barriers to be discussed are those regarding the secondary approach to prevention as they concern the screening for cervical cancer rather than the initial vaccination or treatment efforts.

1. *Individual Barriers*
    a. Individuals in African LMIC populations may have a lower level of knowledge about the disease, its pathogenesis, and the existence and prevalence of screening services in their communities
        i. A meta-analysis of studies done in rural Ghana indicate that women on average said that they weren't aware that screening services were available and where exactly to obtain said services (Binka et al., 2019).
        ii. Community members may not have received information or education on cervical cancer in school or during daily life, therefore making screening less of a priority.
        iii. Many community members have been reported to not know the prevalence and seriousness of cervical cancer, aligning with other studies done in LMICS.
        iv. This lower level of knowledge can also be attributable to overall social stigma against these topics along with inadequate education provided by the community/government.
        v. Due to the knowledge barrier, many women were reported to be afraid of the screening procedure, potential diagnosis/misdiagnosis, and treatment.
    b. There may be misconceptions regarding the cost of screening and treatment with many thinking that the price for screening and treatment procedures are exorbitant
        i. When these misinterpretations of cost are paired with the low incomes of these communities, individuals develop a bias against these services, becoming less willing to participate in cervical screening if available

c. Many community members in African LMICs have personal or psychological convictions against the specific services provided by the government or NGOs.
    i. Some convictions are based in the mistrust of outside organizations coming into communities, built on many years of historic wrongdoings.
    ii. Respondents to surveys have been noted to have a fatalistic mindset regarding cervical cancer based on limited knowledge, thinking that diagnosis will lead to death. These respondents are afraid of the outcome of the screening.
    iii. Some individuals are also scared of the screening procedure itself, believing stories of others who have had a painful experience
        1. Binka and Nyarko, professors at the University of Health and Allied Sciences in Ghana, state "women believed that the insertion of screening instruments into their vagina orifice could be quite painful and unbearable. This may have implications for providing more convenient ways of screening" (2019).

d. Due to the above factors, many women were thus afraid or had apprehensive attitudes towards cervical cancer screening procedures

2. *Community Barriers*
    a. These barriers are related to sociocultural aspects of the specific populations such as belief systems, stigmas, religious convictions, tradition, family structure, and social support.
    b. Additionally, many communities as a whole have sociocultural belief systems that may give rise to misconceptions regarding disease etiology.
    c. Many women especially those that were married or older were shy that male medical personnel may see them naked, contributing to fear.
        i. Paired with perceived unfriendly attitudes, concerns about information/data privacy, and test result confidentiality, these factors have historically kept screening rates low.
    d. Many have been reported to believe that their diagnosis to be a punishment from God for promiscuity or have implications on their marital fidelity.
    e. African LMIC populations are notable for being highly religious/spiritual with organized churches and religious groups having a tangible influence on personal health decision-making
        i. Some groups don't believe in medical treatment and might prescribe traditional methods of healing or will ignore the issue instead.
    f. According to a study on perspectives of eligible women and their partners in rural Kenya, the discussion and results of screening/treatment has caused marital discord.

g. Some female respondents to surveys have stated a lack of spousal support and overall disapproval regarding these issues.
    i. Many husbands report not trusting their spouse and wanting to hear information regarding screening/diagnosis straight from a medical professional.
    ii. Additionally, if diagnosis occurs and women are advised to remain abstinent, some survey respondents have stated their husbands become hostile or non-understanding.

3. *Institutional Barriers*
    a. The main challenges at the institutional level include the attitudes of health personnel, perceived lack of data/record privacy, and large chance of misdiagnosis due to both insufficient provider expertise and inaccuracy of the diagnostic procedure.
        i. The fear of misdiagnosis is also fueled by the personal experiences of many individuals whose perceived ailments have been misjudged and put onto unessential and sometimes harmful treatment programs
    b. In the Pan-African Medical Journal, registered nurses commented on barriers to cervical cancer screening in Eswatini (Mkhonta and Shirinde, 2021).
        i. These nurses noted equipment shortages that limit screening capabilities, poor support/follow up, limited supervision from the program, large queues leading to long waiting times, ineffective booking systems, and a poor lab results system.

4. *Policy Barriers*
    a. Difficulties at this level include inadequate education given to communities by public health organizations, lack of funding set aside for screening/treatment facilities, lack of access to care centers, and unsustainable donor programs.
        i. This is a major issue as Binka and Nyarko note “some respondents reported that they would have gone for screening if they had received adequate education or information on the disease.”
    b. The above was quantified in a study done by Maseko and Chirwa, experts in public health from the University of Malawi Zomba, who examined 21 randomly selected healthcare centers in Malawi (2015).
        i. “Only one health facility was open throughout the week … Six health facilities opened once a week for cervical cancer screening while eight opened twice.”
        ii. 6 of the 21 coordinators reported not having staff on hand to provide cervical cancer care services
        iii. None of the 21 facilities had a professional devoted completely to cervical cancer screening and treatment

iv. In only 4 out of 9 facilities asked about supervision stated that there was much oversight over cervical cancer screening and treatment
v. "48% of the service providers reported to have no stock-out of pharmaceutical products (glacial acetic acid, cotton, gloves, gauze pieces, bleaching powder, detergent, and distilled water) throughout the year in their facilities. Fifty-two percent reported to have one or more stock-outs which could last for a week or more."

c. Some governments have other priorities and do not set aside enough subsidies for women to go get screened
    i. Surveyed women have stated that they would have gone to get screened if not for the fact that they have to pay a portion or the sum out of pocket.

Case Narrative

To paint a more clear picture of the interplay between these four levels of barriers, consider the following narrative. Asale is a Malawian woman living in the Nsanje district of Malawi, poverty-struck and dependent on NGO aid. She lives in a small village with her family outside the town of Bangula. Her formal education as a child was cut short due to her being required to help her family tend to their small farming plot. Growing up, she never received any information about cervical cancer care as her school never covered it because it was regarded as a taboo topic.

Her cousin was screened and reported feeling immense pain, and discouraged others from getting screened. Asale also observed her cousin getting diagnosed and paying out of pocket for both screening and treatment as the government hasn't made solid strides to provide monetary support. Asale also has made the erroneous connection that her cousin's diagnosis was due to the combination of her decision to get screened and her perceived promiscuity as a young adult. The cousin also observed the indifferent and incompetent behavior of the medical staff as well as the deplorable state of the clinic itself, telling the other villagers that she felt as if they made the long journey to Nsanje city for no reason.

Asale is the center of her family but her husband has a final say in all matters. However, she fears her husband's response to her potential diagnosis if she does decide to go get screened, thinking he may get furious and cut off support to the family. All of these factors heavily dissuade Asale from taking the trip to the Nsanje clinic to get screened for cervical cancer. However, little does she know that not only is she genetically predisposed to the disease but that a malignant tumor is already developing. Tragically, she may soon face the consequences of delayed diagnosis.

In this case narrative we see the combination of individual, community, institutional, and policy barriers that discourage Asale from going to get screened for cervical cancer. There are numerous women like Asale and in your team's solution to the case prompt, you should aim to address these barriers.

Social and Economic Impacts to Losing a Woman's Life

Many LMICs in Africa struggle with problems relating to limited resources as well as fragile institutions. These issues reflect in the countries' health systems, which are often structurally fragmented and have ineffective public health efforts. Additionally, these countries struggle with high maternal and child mortality rates, high incidence of chronic illness, malnutrition/undernutrition, and poor standards of living. As a result, chronic non-communicable diseases such as cervical cancer feed into a cycle of poverty. The disability and the premature loss of a woman's life by cervical cancer has a wide social effect on her family and community.

Important to this discussion is the concept of Disability Adjusted Life Years or DALYs. DALYs give a much more complete picture than simple mortality rates of the effect of chronic diseases such as cervical cancer have on populations. According to the WHO, "a DALY represents the loss of the equivalent of one full year of health." LMICs with a low to medium Human Development Index (HDI) have a much higher amount of DALYs lost, a striking difference when compared to nations with high or very high HDIs.

This observation is very troubling as cervical cancer in low-resource settings is known to disproportionately affect women in their prime years, having a significant socioeconomic impact. In many African LMICs, the woman is the center of the household and plays many different, vital roles. Traditionally, there are gender roles which dictate that women should stay in the home to bear/raise children and take care of household duties. However, in recent decades many women also work to support the family, educate their children, and ensure the health of the family as she is the closest to them all. Women in many African societies also have a certain degree of independence afforded to them as they are the centerpiece of household stability. By stabilizing and supporting the family unit, she aims to ensure the success of the family through its wellbeing.

Additionally in society women are central to the "key roles of socialization" and make "relevant albeit underrecognized contributions to the health-care labor force." Moreover, Langer and Meleis, professors at Harvard studying women's health and neonatology, state that women play "crucial roles in the health care of families and communities [as] drivers of the wealth and health of nations." Hence, the high rates of cervical cancer incidence in LMICs paired with poor diagnosis and care leading to higher loss of DALYs, has a tremendous effect in the household.

As a result, children are raised more poorly and without their main support structure, family economic stability is fractured, and there is decreased productivity. Furthermore, “Families are likely to face large medical and non-medical costs, forced to sell assets and accrue debts” during treatment of cervical cancer exacerbating already dire conditions.

Another troubling fact is that many mothers die of cervical cancer with very young children or newborns. Many studies have discussed the effect of inadequate nutrition due to lack of breastfeeding. Additionally, these mothers are not present for the early stages of child development, potentially stunting the health of their children, adding to the already tragic list of consequences of premature death due to cervical cancer.

Health Structures

Africa is the second most populous continent in the world and is divided into 54 independent countries with varying health challenges and needs. While many of the countries face similar health-related challenges, health systems in Africa vary from region to region and country to country due to differences in geographic, political, social, and population-based needs. However, for most countries, the health system is composed of public and private sectors. While state-funded public health is available and caters to the majority of the population, poor infrastructure and lack of resources force many to turn to the private sector (Oleribe et al., 2019; Rensburg, 2021). Yet, many are unable to afford the out of pocket costs associated with private practitioners. For instance, in South Africa, 84% of the population lacks private health insurance but 70% of physicians work in the private sector (de Villiers, 2021).

In addition to only 30% of physicians serving the public sector, residents face another challenge: brain drain. Brain drain is a term used to describe the emigration of trained professionals to other countries (Mo Ibrahim Foundation, 2018). Not only does this pattern deplete human resources to provide healthcare services to local residents, it also puts a strain on the financial infrastructure of spending money to train young workers who end up leaving the country to seek better opportunities. This is particularly relevant in SSA, which is considered one of the poorest areas in the world and comprises many of the least developed countries, according to the Human Development Index (United Nations Development Programme, 2019). Out of the 46 least developed countries determined by the United Nations, 33 are located in Africa (United Nations Conference on Trade and Development, 2021). Even in the Southern region of Africa, which contains some of Africa’s most developed countries, the healthcare infrastructure struggles to provide basic necessities and care for the population and faces structural and financial challenges.

Community Health Workers (CHWs) play a critical role in providing aid for women and children and serve as a link between the community and the healthcare system. As defined by the WHO,

"Community health workers should be members of the communities where they work, should be selected by the communities, should be answerable to the communities for their activities, should be supported by the health system but not necessarily a part of its organization, and have shorter training than professional workers" (World Health Organization, 2007, p.1). Going door-to-door, CHWs pay visits to patients' homes and often treat concerns relating to family planning, malaria, pneumonia, HIV, etc. at a low cost.

Due to systematic challenges, in addition to the lack of access to reproductive healthcare, many women are not treated for cervical cancer until it has reached an advanced stage. According to the WHO, there are particularly high prevalence rates of cervical cancer among women in the Southern African region with an incidence rate of 36.4 per 100,000 in 2020 compared to the global rate of 13.3 (World Health Organization, 2020). Specifically, Eswatini (Kingdom of), Malawi, and South Africa ranked first, second, and fourteenth respectively in highest incidence rates in the world in 2018 (World Cancer Research Fund). Information about each country is presented below (The World Factbook, 2021).

	Eswatini	**Malawi**	**South Africa**
Population (July 2021)	1,113,276	20,308,502	56,978,635
Population growth rate (2021 est.)	0.77%	2.39%	0.95%
Area	17,364 sq km	118,484 sq km	1,219,090 sq km
GDP (2019 est.)	$4.484 billion	$7.766 billion	$350.032 billion
Real GDP per capita (2019 est.)	$8,622	$1,060	$12,482
Population below poverty line (2014-16 est.)	58.9%	51.5%	55.5%
HDI (2019)	0.611 (Medium human development)	0.483 (Low human development)	0.709 (High human development)
Cervical cancer incidence rate* (2018)	75.3 per 100,000	72.9 per 100,000	43.5 per 100,000 (2018)
Ethnic Groups (2018	• Predominantl	• Chewa:	• Black African:

est.)	y Swaz • Smaller populations of other African ethnic groups, including the Zulu, as well as people of European ancestry	34.3% • Lomwe: 18.8% • Yao: 13.2% • Ngoni: 10.4% • Tumbuka: 9.2% • Sena: 3.8% • Mang'anja: 3.2% • Tonga :1.8% • Nyanja: 1.8% • Nkhonde: 1% • Other: 2.2% • Foreign: 0.3%	80% • Colored*: 8.8% • White: 7.8% • Indian/Asian: 2.5%
Languages	• English • siSwati	• English (official) • Chewa (common) • Lambya • Lomwe • Ngoni • Nkhonde • Nyakyusa • Nyanja • Sena • Tonga Tumbuka • Yao	• isiZulu (official) • isiXhosa (official) • Afrikaans (official) • Sepedi (official) • Setswana (official) • English (official) • Sesotho (official) • Xitsonga (official) • siSwati (official) • Tshivenda (official) • isiNdebele (official) • other (includes Khoi, Nama, and San languages)
Religions (2018 est.)	• Christian: 90% • Other: 8% • Muslim: 2%	• Protestant: 33.5% • Roman Catholic: 17.2% • Other Christian:	• Christian: 86% • Ancestral,tribal,animist/other traditional African religions: 5.4% • Nothing in

		26.6% • Muslim: 13.8% • Other: 5.6% • None: 2.1% • Traditionalist: 1.1	particular: 5.2% • Muslim: 1.9% • Other: 1.5%
Age Structure (2020 est.)	• 0-14 years: 33.63% • 15-24 years: 18.71% • 25-54 years: 39.46% • 55-64 years: 4.36% • 65+ years: 3.83%	• 0-14 years: 45.87% • 15-24 years: 20.51% • 25-54 years: 27.96% • 55-64 years: 2.98% • 65+ years: 2.68%	• 0-14 years: 27.94% • 15-24 years: 16.8% • 25-54 years: 42.37% • 55-64 years: 6.8% • 65+ years: 6.09%
Median Age (2020 est.)	23.7 years	16.8 years	28 years
Urban Population (% of total population)	24.4%	17.7%	67.8%
Rural Population (% of total population)	76%	83%	33%
Percentage of women	50.8%	50.7%	50.7%
Life expectancy at birth (2021 est.)	• Total population:59.13 years • Male: 57.05 years • Female: 61.28 years	• Total population: 72.16 years • Male: 69.04 years • Female: 75.33 years	• Total population: 65.04 years • Male: 63.68 years • Female: 66.42 years
Current Health Expenditure** (2018 est.)	6.5%	9.3%	8.3%
Physicians density (2016-2018 est.)	0.33 physicians/1,000 population	0.04 physicians/1,000 population	0.91 physicians/1,000 population

HIV/AIDS adult prevalence rate* ** (2020 est.)	26.8%	8.1%	19.1%
Literacy Rate (age 15 and over can read and write) (2015-2017 est.)	88.4%	62.1%	87%
Government type	Absolute monarchy	Presidential Republic	Parliamentary Republic

*Compared to developed countries such as Australia, which estimates 7.0 cases per 100,000 in 2020, and the United States which estimates 7.5 cases per 100,000 in 2018 (Australian Government, 2020; Centers for Disease Control and Prevention, 2018).
**According to the World Factbook, "Current Health Expenditure (CHE) describes the share of spending on health in each country relative to the size of its economy. It includes expenditures corresponding to the final consumption of health care goods and services and excludes investment, exports, and intermediate consumption" (2021).
***According to WHO, "Compared with women who are HIV-negative, women living with HIV have a risk several times higher of persistent HPV infection, are six times as likely to develop cervical cancer and are more likely to develop it at a younger age" (2020).

An Innovative Solution: Microbead Technology in HPV Screening

The primary method of screening protocols for cervical cancer is the Papanicolau (Pap) smear. The Pap smear involves the collection of a cell sample from the cervix in order for medical providers to detect any changes (specifically, HPV virus) in the patient's cervical cells that might suggest the future development of cancer. The utility of the Pap smear has been long-lived because these routine tests allow for early detection of these abnormal cells to expedite the process of obtaining a cure for cervical cancer.

However, the increased usage of technology in the medical field has encouraged the development of various advancements in cervical cancer protocols. These nanotechnologies and machine learning techniques are on the rise and will soon replace the traditional Pap smear because they are more accurate in identifying abnormal cells that indicate future risk for cervical cancer. The Pap smear is not always a reliable indicator of future risk for cervical cancer because it is only "80% accurate if administered regularly." Conducting these routine tests also requires "high-quality laboratories, properly trained clinical doctors and repeated screenings for maximum accuracy and efficiency" (Dunleavy 2021), conditions which are not widely available in LMICs.

A novel technique that attempts to address these barriers involves exposing a cell sample from the cervix to tiny beads made of biological material. Upon exposure, the beads change conformation to a diamond shape when they come in contact with the HPV virus. The conformational changes in the beads would normally be detected with a powerful microscope, but in healthcare settings where they are not available, "a mobile phone app, built through machine learning, can be used to read them" (Pittcon 2018).

The principle of holography is currently being implemented so that smartphones are able to detect indicators of cancer on certain cell samples. A holographic pattern is created on the mobile device when light strikes the cell sample. Pre-constructed cloud algorithms are then used to decipher these light patterns and the cell sample's interactions with the molecular beads so that cancer-specific markers can be identified (Pittcon 2018). The cell sample is placed on a small attachment over the smartphone camera lens and the light patterns are then stored in a cloud and reconstructed, thus allowing the provider to identify cancer-specific markers.

Using the smartphone as the platform for executing this new microbead technique is predicted to be able to bring incredibly rapid, accurate, and cost-effective molecular diagnoses of cancer at the "point of care" to patients lacking access to facilities with the latest medical technology. The smartphone can enable analysis of data at a rate of "as much as 10 MB in less than nine-hundredths of a second" (Kurzweil 2015) allowing for rapid determination of the presence of abnormal cell tissue. In addition to the rapid diagnosis determination, the smartphone device provides a means for more accurately identifying the specific regions in which cancer might be present since the device is able to image individual cells and cancer markers unique to each of them as opposed to large sections of tissue being examined. The cost-effectiveness of this new technology is also proven in a pilot test of the device: "results of the assay were available in under an hour and at a cost of $1.80 USD per assay, a price that would be expected to drop with further refinement of the system" (Kurzweil 2015). The price of a regular Pap smear is between $25 and $40 USD.

This technology can be quite transformative in many low-resource healthcare settings. The innovation is user-friendly, non-invasive, and cost effective thus allowing communities to retain sustainable preventative measures for lethal diseases like cervical cancer. However, despite the abundant advantages of this novel screening method, the implementation of it in low-resource healthcare settings must "align with existing clinical workflows" and "ideally increase the overall throughput of results" (Castro 2018).

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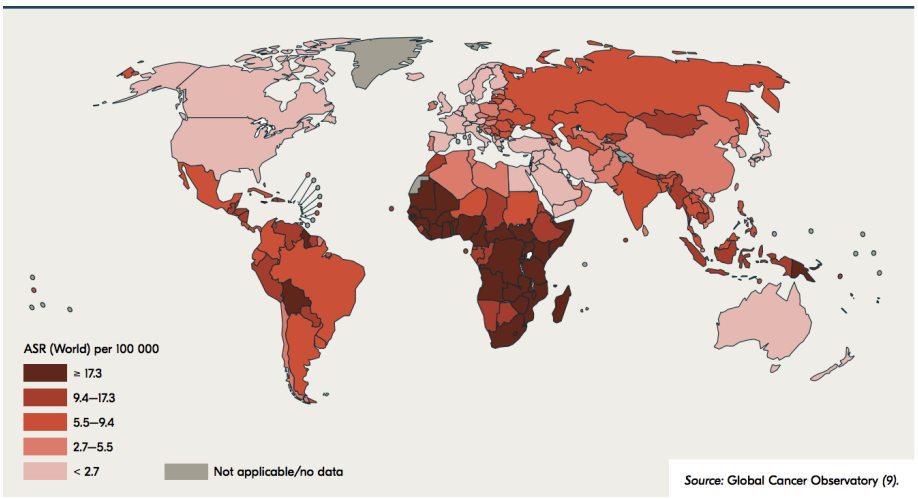
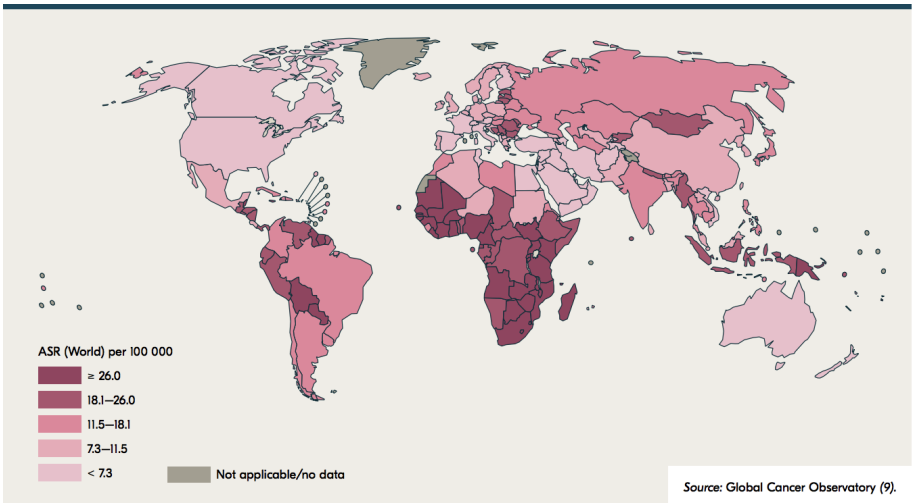
Appendices

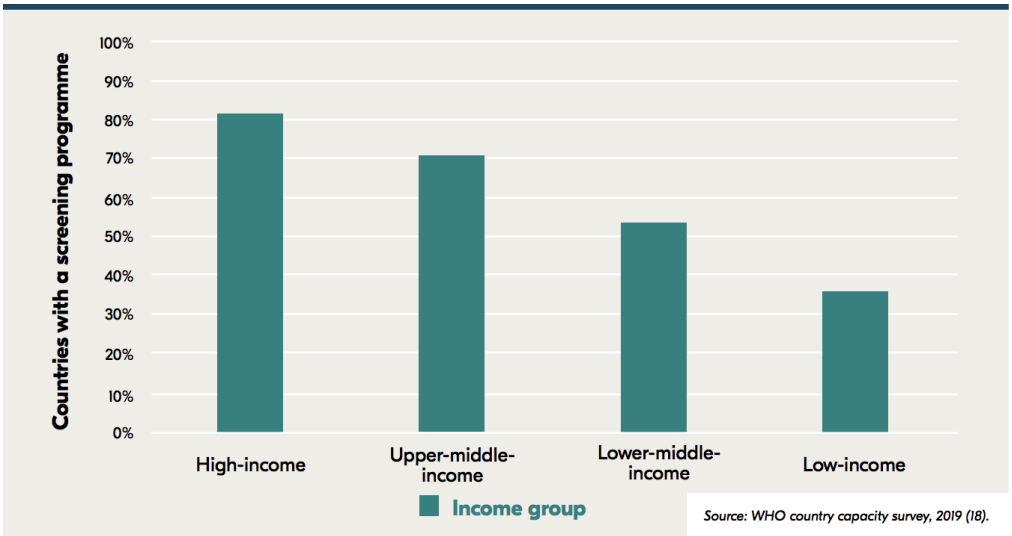
Appendix 1. Estimated Age-Standardized Cervical Cancer Incidence, 2018 (The World Health Organization)



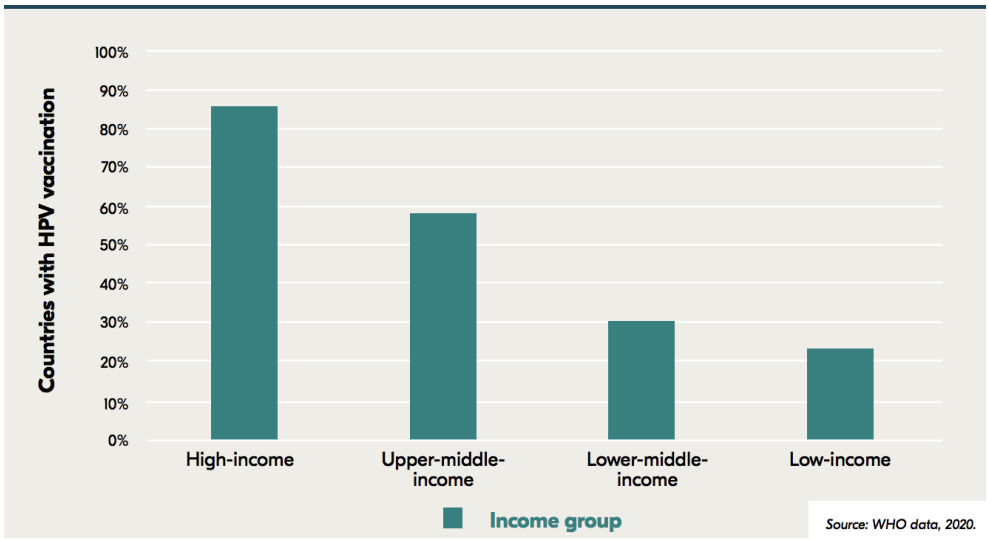
Appendix 2. Estimated Age-Standardized Cervical Cancer Mortality, 2018 (The World Health Organization)



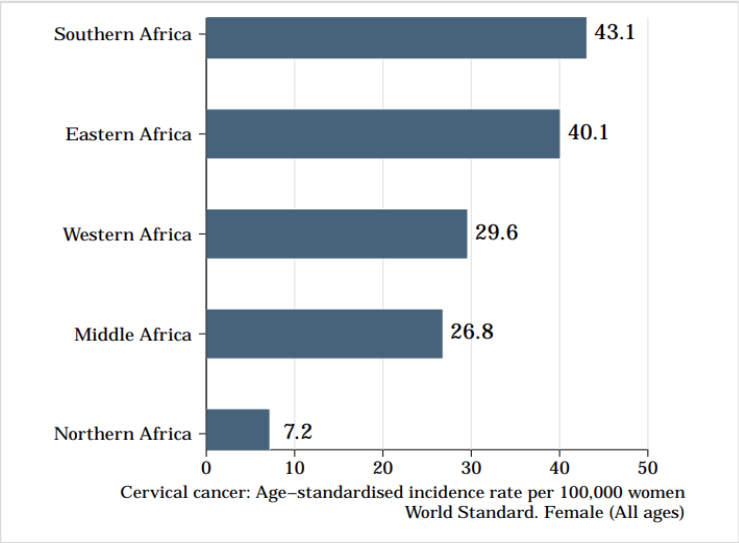
Appendix 3. Percentage of Countries with a National Cervical Cancer Screening Programme, by World Bank Income Group, 2019
(World Health Organization Country Capacity Survey)



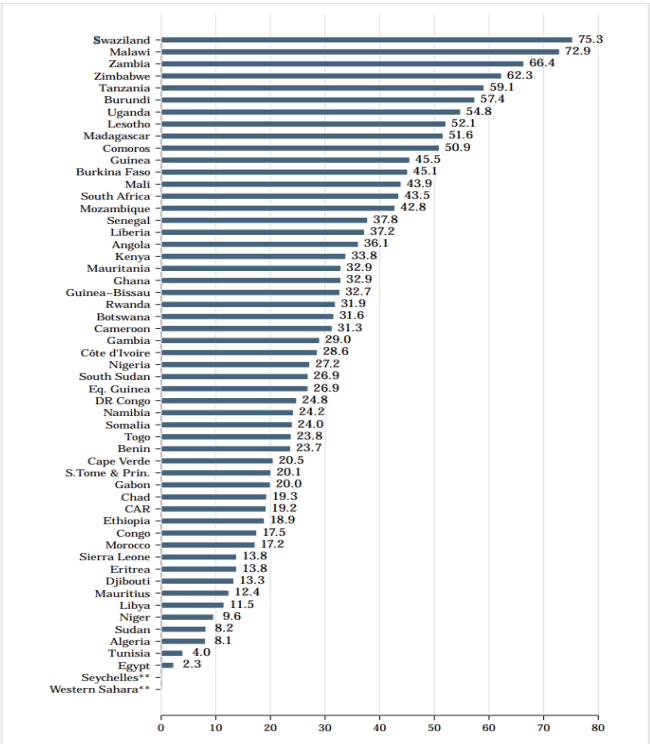
Appendix 4. Percentage of Countries with HPV Vaccine in the National Immunization Schedule, by World Bank Income Group, 2020
(World Health Organization data)



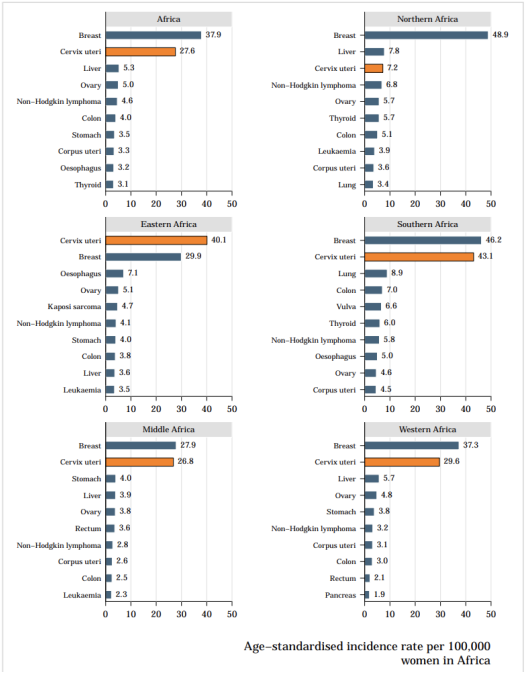
Appendix 5. Age-standardised Incidence Rates (ASR) of Cervical Cancer in Regions of Africa, 2018
(HPV Information Centre)



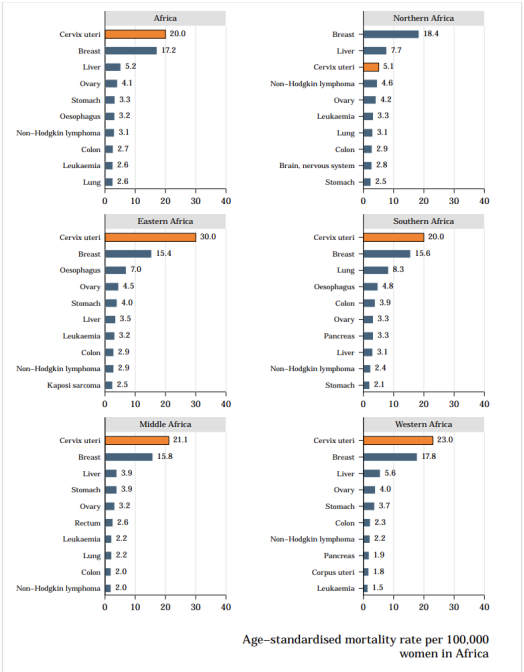
Appendix 6. Age-standardised Incidence Rate of Cervical Cancer Cases Attributable to HPV by Country in Africa, 2018
(HPV Information Centre)



Appendix 7. Comparison of the Ten Most Frequent Cancers in All Women in Africa and Its Regions, 2018
(HPV Information Centre)



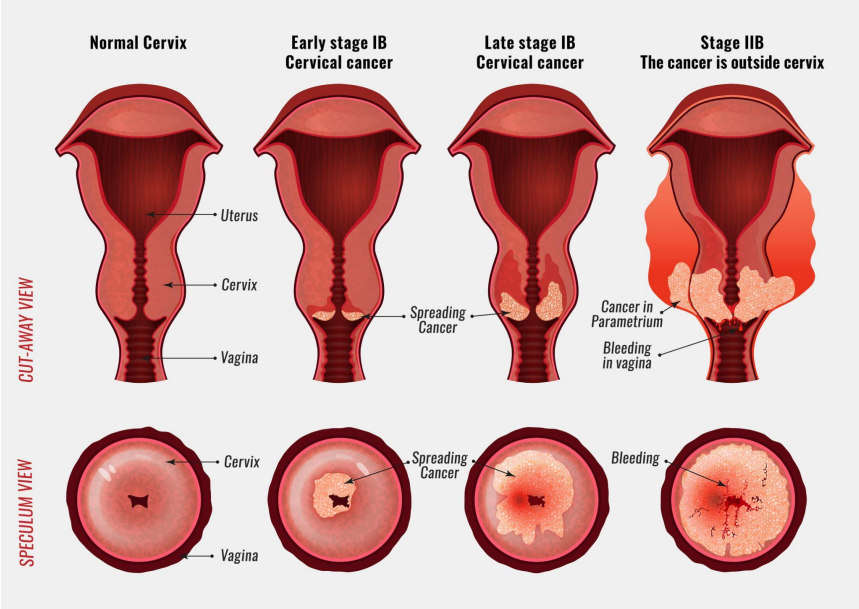
Appendix 8. Comparison of the Ten Most Frequent Cancer Deaths in All Women in Africa and Its Regions, 2018
(HPV Information Centre)



Appendix 9. HPV Vaccination Policies for the Female Population in Africa, 2016 (HPV Information Centre)

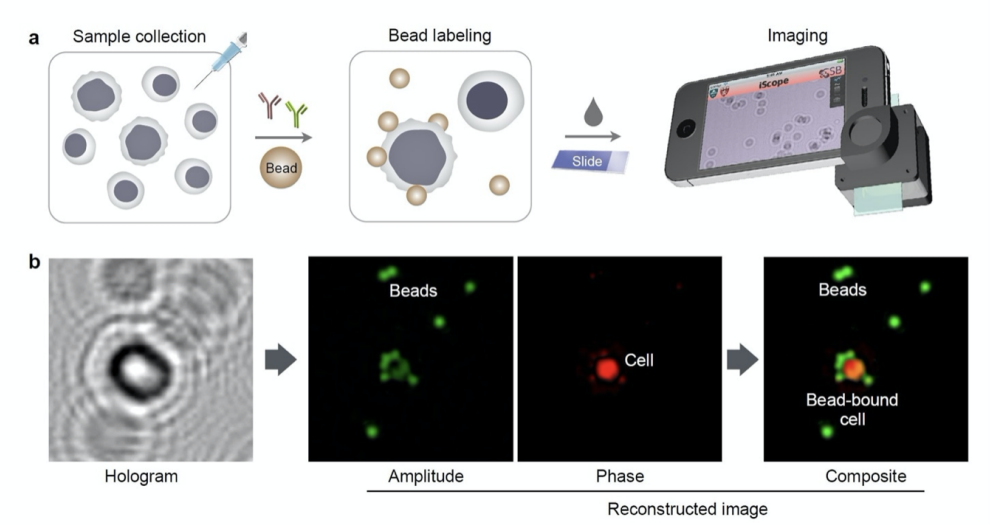
	Routine Immunization	
Country	**HPV vaccination programme**	**Date of start**
Algeria	No program	-
Angola	Announced	-
Benin	Pilot	-
Botswana	National program	2015
Burkina Faso	Pilot	-
Burundi	Pilot	-
Cameroon	Announced	-
Cape Verde	No program	-
Central African Republic	No program	-
Chad	No program	-
Comoros	No program	-
Congo	No program	-
Côte d'Ivoire	Pilot	-
Democratic Republic of the Congo	No program	-
Djibouti	No program	-
Egypt	No program	-
Equatorial Guinea	No program	-
Eritrea	No program	-
Ethiopia	Pilot	-
Gabon	No program	-
Gambia	Pilot	-
Ghana	Pilot	-
Guinea	No program	-
Guinea-Bissau	No program	-
Kenya	Announced	-
Lesotho	National program	2012
Liberia	Pilot	-
Libya	National program	2013
Madagascar	Pilot	-
Malawi	Announced	-
Mali	Pilot	-
Mauritania	Pilot	-
Mauritius	No program	-
Morocco	No program	-
Mozambique	Pilot	-
Namibia	No program	-
Niger	Pilot	-
Nigeria	Pilot	-
Rwanda	National program	2011
Sao Tome and Principe	National program	2016
Senegal	National program	2016
Seychelles	National program	2014
Sierra Leone	Announced	-
Somalia	No program	-
South Africa	National program	2014
South Sudan	No program	-
Sudan	No program	-
Swaziland	No program	-
Togo	Pilot	-
Tunisia	No program	-
Uganda	National program	2012
United Republic of Tanzania	Pilot	-
Western Sahara	No program	-

Appendix 10. Cervical Cancer Stages and Progression
(Singing River Health System)



Appendix 11. Pap Smear Equipment
(Medline)

Appendix 12. Microbead Technology (News-Medical)



Molecular detection with holography. (a) Schematic of holographic assay for cancer cells collected by fine needle aspiration. (b) A hologram image is reconstructed for complementary amplitude and phase contrast images. The amplitude (green) and phase contrast (red) images are pseudocolored for better visualization of cells and beads.